U.S. DEPARTMENT OF COMMERCE

PB80-176258

Proceedings of the First Symposium on Iron and Steel Pollution Abatement Technology, Held at Chicago, Illinois on October 30-November 1, 1979

Research Triangle Inst.
Research Triangle Park, NC

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Feb 80

U.S. Department of Commerce
National Technical Information Service
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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/9-80-012	2.	3. RECIPIENT'S ACCESSION NO. PB80 176258
4. TITLE AND SUBTITLE Proceedings: First Symposium on Iron and Steel Pollution Abatement Technology (Chicago, IL, 10/30-11/1/79)		5. REPORT DATE February 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Franklin A. Ayer, Compiler		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P.O. Box 12194 Research Triangle Park, North Carolina 27709		10. PROGRAM ELEMENT NO. 1AB604 11. CONTRACT/GRANT NO. 68-02-2630, Task 6
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Proceedings; 3/79 - 2/80 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Robert C. McCrillis, Mail Drop 62, 919/541-2733.

16. ABSTRACT The report documents presentations at the first EPA-sponsored symposium devoted solely to pollution abatement technology for the iron and steel industry, held in Chicago, IL, October 30 - November 1, 1979. The symposium was organized into air, water, and solids sessions. Air pollution topics included: emission standards, assessment of coke quench tower and by-product recovery plant emissions, sealing of coke-oven doors, volatilization of hydrocarbons in steel rolling operations, development of a coke-oven air pollution control cost effectiveness model, control of sinter plant emissions utilizing recirculation of windbox gases, estimating fugitive contributions to ambient particulate levels near steel mills, foreign technology for BOF fugitive emission control, and fugitive particulate emission factors for BOF operations. Water topics included emission standards, total recycle of water in integrated steel mills, use of spent pickle liquor in municipal sewage treatment, physical/chemical treatment of steel plant wastewaters using mobile pilot units, foreign technology forcontrolling coke plant and blast furnace wastewaters, and formation and structure of water-formed scales. Solid waste topics included emission standards, environmental and resource conservation considerations of steel industry solid waste, and de-oiling and utilization of mill scale.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Mathematical Models	Pollution Control	13B	12A
Iron and Steel Industry		Stationary Sources	11F	
Emission	Sintering	Emission Standards		
Assessments	Dust	Fugitive Dust	14B	11G
Coking	Waste Disposal		13H	
Hydrocarbons	Chemical Cleaning		07C	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

PB80-176258

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/9-80-012
February 1980

Research and Development

EPA

Proceedings: First Symposium on Iron and Steel Pollution Abatement Technology (Chicago, IL, 10/30-11/1/79)

Interagency Energy/Environment R&D Program Report

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EPA-600/9-80-012

February 1980

Proceedings: First Symposium on Iron and Steel Pollution Abatement Technology (Chicago, IL, 10/30-11/1/79)

Franklin A. Ayer, Compiler

Research Triangle Institute
P.O. Box 12194
Research Triangle Park, North Carolina 27709

Contract No. 68-02-2630
Task No. 6
Program Element No. 1AB604

EPA Project Officer: Robert C. McCrillis

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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ABSTRACT

The proceedings for the "Iron and Steel Pollution Abatement Technology" symposium constitute the final report submitted to the Industrial Environmental Research Laboratory by the Research Triangle Institute in fulfillment of Contract Number 68-02-2630, Task 006. The symposium was held at the Pick-Congress Hotel, Chicago, Illinois, October 30, 31, and November 1, 1979.

The purpose of this first EPA-sponsored symposium was to serve as a forum for the exchange of information on environmental assessment and pollution abatement technology development and demonstration in the iron and steel industry.

This publication contains the text of all papers presented at this symposium. Papers cover significant multimedia programs conducted by the iron and steel industry, research organizations, and governmental agencies.

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PREPARED FOR DELIVERY BY

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ASSISTANT ADMINISTRATOR
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AT THE
IRON AND STEEL POLLUTION ABATEMENT TECHNOLOGY SYMPOSIUM
CHICAGO, ILLINOIS

OCTOBER 29, 1979

SPONSORED BY
ENVIRONMENTAL PROTECTION AGENCY

As I flew into Chicago to address this conference on pollution control in the iron and steel industry, I remembered the first time I saw Chicago. I was fifteen, coming east for my first trip off the plains of Nebraska. As we approached Chicago, dusk was falling and the setting sun illuminated the billowing red clouds of pollution from south Chicago and Gary like an eruption directly up from hell. Still fairly fresh from the clean skies of the prairies, I was awed by that overwhelming scene.

Now from the perspective of a few more years, I remain as equally impressed, as I was those twenty-five years ago, with how far we've come and how far we still must go. Not all of the conventional air and water pollution problems have been solved by the iron and steel industry, but many have and the citizens of Chicago and Pittsburgh are much the better off for those advances. We must now deal with a tougher problem, the invisible intrusion of thousands of toxic chemicals into the environment--a commitment as challenging as the first commitment to rid our environment of the obvious noxious pollutants. I am very pleased to note that this is a "multimedia" conference indicating that we in the Environmental Protection Agency, as well as you in the iron and steel industry, recognize that potential pollution problems exist in the air, in the water, and on land. The interrelationship among these three media must be clearly understood as we attempt to solve pollution problems. For example, we may solve an air pollution problem only to create a severe water pollution problem in the process. Also, we are finding more and more alarming cases where toxic materials improperly disposed of in landfills and lagoons are leaching out and polluting local surface and ground waters.

I am also pleased to welcome EPA's Offices of Air Quality Planning and Standards, Water Planning and Standards, Solid Waste Enforcement. With this broad agency representation, we should give broad visibility to the breadth of our environmental problems. The role of the Office of Research and Development in supporting the entire agency is certainly highlighted by the participation of the regulatory offices.

In general, the participants in this symposium represent a wide diversity of interests--government, the iron and steel industry, universities, engineering firms, and equipment vendors. This is a healthy sign since no single sector has a monopoly on knowledge. To advance toward a common goal of controlling pollution problems wherever they exist and to do so in an efficient and cost-effective manner requires a pooling of our common knowledge and expertise. We, in Washington, know full well that we cannot by ourselves solve environmental problems; and we also know that given the nature of our open, pluralistic society, there's going to be a lot of tugging and pulling over what gets cleaned up and when. That's why Congress gave up the job of setting and enforcing national environmental standards and regulations.

Ambient environmental standards and industrial discharge regulations are established after a long period of research by both industrial and governmental laboratories; after extensive review of scientific research and economic data; and after extended public scrutiny by outside experts in technology, health effects and economics. These standards are, therefore, the best reflection of what we know about the short-term and long-term health and environmental effects of the pollutants and the technology available to abate those pollutants. They are based on the best data we can find. So, as new data become available, it is essential that this information be transferred to involved government agencies, to private scientific groups, and to industries at the earliest possible moment. We all need to be aware of the latest research data, so that standards can be established on a common up-to-date base of technical knowledge.

As you know, the setting of environmental standards and regulations is a very complex process involving numerous government and private scientific groups, industries, and the public at large. It is thus impossible to make decisions that will satisfy everyone. But since these decisions must be made on a rational, scientific basis, conferences such as this serve as a sounding board for scientific thought, where industry, universities, and government may exchange ideas and develop new ones.

Court cases drain the resources of both industry and the taxpayer. When possible, it is better to attempt to resolve problems and obtain a consensus at the scientific roundtable than to test the decisions at a judge's bench.

Despite best intentions on both sides, however, EPA and the iron and steel industry have been, on many occasions, antagonists. Recently we have been at loggerheads with the industry over its insistence that even handwritten drafts of chapters for the sulfur oxides criteria document are subject to discovery, a claim we felt verged on harassment, but we'll probably work out a solution to that issue eventually. On the other side of the ledger, EPA and several major steel companies have negotiated landmark settlements in air and water pollution cases which have been dragging for years. Encouraging, too, is the fact that there have been a number of instances of joint technical effort to develop new pollution abatement technology. An excellent example of this is the jointly funded coke oven door seal project. While it is the nature of our system of government that we shall find ourselves frequently viewing issues from different vantage points, we must continue to work together whenever feasible so we can proceed down the road towards a cleaner environment.

I know there is much skepticism on the part of many persons concerning the work of EPA. There have been charges by industry that we are moving too fast and too soon with too little data on which to base decisions. We are further accused of putting industry "out of business" because of excessive pollution control costs.

However, while it does cost money to protect our health and environment, the cost of pollution control contributes less than one-half of one percent to the annual rate of inflation. Pollution control also creates more jobs than it displaces.

Industry is not the only segment of our society that is dissatisfied with what we, at EPA, are doing. Environmental groups, by contrast, accuse EPA of not moving fast enough. They say too little has been accomplished. Here again, the record shows that we are making progress: Fish are returning to our lakes and streams. As an example, Atlantic salmon are returning to the Connecticut River for the first time in years. Fish and other aquatic life are returning to the Cuyahoga River, the Buffalo River, the Detroit River, and the Houston Ship Channel. There's even a new sport emerging in downtown Washington these days--bass fishing in the Potomac within the shadow of the Kennedy Center. And the fishing's good!

Similar improvements have been made in reducing air pollution: Carbon monoxide levels have fallen, particulate emissions have been reduced, and SO_x levels are measurably smaller. Hopefully, these trends will continue.

The role of a governmental regulatory agency--whatever it is regulating--is never one that is cheered and acclaimed from all sides. However, as our population grows, as our national economy grows, and as we move to greater use of our domestic energy resources, we must remember that our air, water, and land resources are not growing. The additional health and environmental pollutants being generated by such growth must be adequately controlled. Also, as additional hazards are recognized, the regulations may have to become more and more stringent. But we are looking for innovative ways to regulate and control pollution that will not impede growth or reduce our standard of living.

Our standard of living is, in no small measure, dependent on steel. There are about 130 steel-making plants in the U.S. centered in the traditional steel-producing districts such as Pittsburgh and Chicago. Over 75% of total U.S. steel output is accounted for by the six states bordering the Great Lakes. U.S. iron and steel plants employ upwards of a half million persons and produce products whose gross sales amount to $40 billion annually. Keeping this industry healthy is of vital importance to this nation. But we must also keep our people healthy. We must review each phase of industry operations to keep air, water, and land pollutants within safe limits.

The making of coke from coal, the reduction of iron ore to iron, and the refining of the iron and melting of scrap to produce steel all have the potential for emitting vast quantities of air pollutants.

Loading, unloading, transfer, and storage of raw materials can also result in the entrainment of dust. Careful attention to process variables, operating practices, and maintenance schedules can, in some cases, achieve adequate control. Often, however, these efforts must be combined with the addition of control equipment or significant process modifications.

The downstream forming and finishing operations require vast quantities of water for cooling, lubrication, and cleaning. Control of water pollutants requires the addition of control equipment. To do this at reasonable cost, however, process modifications are needed so that the net flow of contaminated water to the treatment plant will be reduced. Recycle appears to be an essential element for good water pollution control. As we move towards increased control of pollutants, discharge flows must be reduced by increasing in-plant recycling of water wherever possible.

All these controls on air and water, of course, also yield solid wastes. Emphasis is being placed on technology to permit returning more of these materials back into the steel-making process, but there will still be some solid wastes which must be disposed of in an environmentally sound manner.

I will not dwell on the regulations controlling these pollutants here, because I am certain they will be discussed in detail later in the program. But I would like to call special attention to the agency's attempt to control toxic chemicals discharged into the environment by industry.

In 1976 a consent decree, settling a court suit filed under the Federal Water Pollution Control Act, was signed by EPA and four environmental groups. EPA agreed to set effluent standards for 65 classes of compounds for 21 industries--including the iron and steel industry. As a result, the Effluent Guidelines Division of EPA published a list of 129 organic pollutants and metals on which they proposed to set regulations. These have since become known as the "priority toxic pollutants." Subsequently, amendments to the water pollution legislation, known as the Clean Water Act of 1977, converted the terms of the consent decree into law. Specifically, the 1977 Act requires the application of best available technology economically achievable (BATEA) to control the priority pollutants by July 1, 1984.

We recognize that these regulations, plus the advent of the Resource Conservation and Recovery Act, the Toxic Substances Control Act, pretreatment standards of the Clean Water Act, and the 1977 amendments to the Clean Air Act place a great burden on the iron and steel industry. However, we are also aware of the progress the iron and steel industry is making toward solving the problems associated with meeting these standards. Systems for recycling blast furnace scrubber water are becoming more common, as is biological treatment of coke plant waste waters. Many plants are implementing staged charging and are placing pushing-emission-controls on their coke batteries.

We recognize that the iron and steel industry faces economic problems, such as its low profit margin and the threat of foreign imports, which are generally more intractable than the economic pressures created by pollution control requirements.

We are looking to economic regulatory reforms to help ease the regulatory burden. We believe they will provide positive incentives for industry to invest in developing new, more efficient forms of control technology and practices. As many of you are probably aware, Douglas

Castle, EPA's Administrator, has been prominent in this effort not only at EPA, but across the board in all federal regulatory activities. He has been appointed Chairman of President Carter's Regulatory Council, which is comprised of all the federal department agency and independent regulatory commissions. The purpose of the Council is to search for alternative approaches to make regulation less burdensome on business--without reducing benefits to the public.

We at EPA have been in the forefront of this federal effort and have developed a number of new regulatory reform initiatives. We have been encouraged by the response to them and the results that have been achieved. I'd like to close with a brief description of these new regulatory approaches--the "bubble approach," an offset policy, and performance standards.

Early this year EPA proposed a new policy to give industry greater flexibility in meeting air pollution requirements. This policy--known as the "bubble approach"--would allow a firm to devise its own methods of cleaning up individual polluting sources within a plant facility.

Picture a giant plastic bubble placed on a steel mill--over all the buildings and surrounding on-site facilities. At the top of the bubble is a single hole through which all the plant's pollution escapes.

Up to now to control this pollution what we have been doing is to put limits on emissions from each source in the facility. Under the bubble approach, the only pollution measurement would be taken at the top of the bubble. Plant management could control pollution from individual sources within the facility as they saw fit, so long as the air escaping from the top of the bubble met federal standards. Managers might choose to omit controls from particularly difficult sources while installing stricter controls on easier sources.

For example, in Pennsylvania, agreement was reached among U.S. Steel Corporation, EPA, and the Pennsylvania Department of Environmental Resources to allow trade-offs in controlling particulates emitted by their furnaces. In another case last June, E. I. DuPont Company proposed to clean up its hydrocarbon emissions at one of its chemical plants in New Jersey. Using the standard controls approach, it would cost $20 million and achieve an 85% reduction in hydrocarbons. Using the bubble approach, the company said it could remove 90% of its hydrocarbons at a cost of only $5 million.

As Doug Castle said at the announcement, "This policy will mean less expensive pollution control--not less pollution control."

This basic approach has also been extended to cover not only a single plant, but also several facilities in a particular area, where trade-offs might be possible. In effect, the so-called "offset" policy treats entire regions as gigantic bubbles, requiring only that overall air standards be met for the region. This approach allows major modifications or new facility construction, provided the additional pollution generated is offset by reductions elsewhere--either within a facility or at nearby facilities.

In some cases, companies have been willing to pay large sums of money to control pollution at nearby plants so that they could proceed with construction of their own new facilities. In others, companies have advised local government officials that they would invest in building new large plants in the area if the governmental agencies could find offsetting reduced pollution sources. Oklahoma City and Shreveport, Louisiana, are two examples of where municipal governments have persuaded other companies to reduce their emissions to make room for new plants.

Another variation in this offset polity is a recent amendment that allows "banking" of air pollution offsets. This has come about because of the possibility that state agencies might insist on requiring offsets that would be far greater than the expected pollution generated by new construction. Under this policy, a company may "bank" any excess emissions reductions it makes and use them to offset future expansion.

We also see the potential for this concept to be expanded to cover an entire air pollution region. Local or state governments could set up offsets banking accounts for companies in their jurisdiction to keep track of each agreement made to reduce source emissions. A statement of account balances would be maintained that could be drawn upon for future industrial expansion. This kind of a centralized accounting would also facilitate any future searches by industry and local government officials for offsetting sources.

These approaches we are taking are part of a broader federal regulatory policy of setting performance standards, rather than specifying detailed means to meet the performance goals.

Any of these schemes that substitute economic incentives for specific, detailed regulations help to stimulate technological innovations. They also allow industry to select the least costly measures for pollution abatement. These incentive approaches can result in economic, environmental, and social advantages over the more traditional regulatory approaches.

The traditional "command and control" regulations are being reviewed and alternatives are being tested. By enlisting the support and cooperation of industry through these incentives, we can hopefully tie America's economic genius to its technological and scientific expertise. Through conferences such as this, we are seeking to promote technological innovations for pollution control--to stimulate a freer exchange of scientific and technical information--and to develop regulatory policies that will protect the health and environment at minimum cost to industry and the public.

OPENING SESSION

General Chairman: Robert C. McCrillis, Mechanical Engineer
Metallurgical Processes Branch
Industrial Processes Division
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC

Statement of Symposium Objectives

Robert C. McCrillis

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

Good morning, ladies and gentlemen:

I am Bob McCrillis, your Symposium General Chairman. Your program states that this "Symposium is designed to serve as a forum for the exchange of information on environmental assessment and pollution abatement technology development and demonstration in the iron and steel industry." During the next 2-1/2 days you will be subjected to a barrage of information on iron and steel projects ranging in scale from laboratory research to full-scale operating units. You will be presented detailed engineering, emission and cost data obtained during actual full-scale operation, and you will also hear the results of engineering paper studies.

The program is subdivided into three sessions with the three media. Although the air session is much longer than either of the other two, this should not be construed to mean that EPA places more emphasis on this media. Rather, it is simply an artifact of the past when MPB was oriented to air only. We are now multimedia and as time goes by, our program has become more evenly balanced. Future symposia will reflect this balance. We are also considering encouraging more participation from persons outside the EPA-sponsored sphere. In addition, future symposia may be expanded to include a fourth session devoted to noise. We will, of course, continue to stress technical content as you will see over the next 2-1/2 days.

Each author has been allotted 35 minutes of which about 20-25 minutes is for his presentation and 10-15 minutes for questions from the audience. I heartily encourage your participation in the question-and-answer period; however, in all fairness to subsequent authors, session chairmen will cut off questions at the end of the allotted time.

This symposium is sponsored by the Metallurgical Processes Branch of EPA under the able leadership of Norman Plaks, whom you will meet in just a moment. Along with the other members of the Branch who are Bob Hendriks, John Ruppersberger, and Susan Sharpe, I encourage you to give us your comments on the symposium itself so that we may improve our future productions.

EPA's Iron and Steel Program

Norman Plaks
U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

Presented at the Symposium on Iron and Steel
Pollution Abatement Technology

Chicago, Illinois

October 30 - November 1, 1979

BACKGROUND

The Environmental Protection Agency's multi-media research and development program for ferrous metallurgical processes is centered at its Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina. The concern of the program is for the integrated iron and steel industry, iron and steel foundries, and ferroalloys.

The air portion of the program, which was started in 1968, has its roots in the National Air Pollution Control Administration of the Department of Health, Education and Welfare. The water portion of the program, which was started in 1966, traces its antecedents back to the Federal Water Pollution Control Administration of the Department of the Interior. Both became part of the Environmental Protection Agency when the Agency was established in December 1970. Until the enactment of the Resource Conservation and Recovery Act of 1976 there had been little basis for undertaking systematic work in solid waste treatment.

At the time the iron and steel air program was started, the authorizing legislation did not mandate specific control levels and schedules to be achieved. However, it did stipulate that R&D was to be done. Prioritization for the R&D was based upon a study by Battelle entitled, "A Systems Analysis Study of the Integrated Iron and Steel Industry,"* published in 1969, which indicated that emissions from the manufacture of coke should have the highest priority for R&D. Other processes identified as having high priority for R&D, because of their emissions, were charging of basic oxygen furnaces, sinter plants, blast furnace cast houses, and both process and open source fugitive emissions in general. In response to the Battelle prioritization a number of projects were undertaken between 1968 and 1975. (See Table 1)

Three milestones were established within the general wastewater treatment program, which included iron and steel, by the Clean Water Restoration Act of 1966. These were 1) to develop the technology necessary to achieve the equivalency of secondary treatment (85 percent BOD removal), 2) to achieve state water quality standards (95 percent BOD removal), and 3) eventually to eliminate all water pollution caused by industry. Again, much like in the air program, a schedule for achieving these levels of reductions was absent in the legislation. However, projects were undertaken to achieve these levels of discharge reduction for the most significant sources in the iron and steel industry (See Table 2). Included was work in treating of wastewaters from cokemaking, blast furnaces, finishing, and other sources from the integrated iron and steel industry.

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*EPA Report No. APTD 1177 (NTIS No. PB 184 576), May 1969

In July 1975 a reorganization in the EPA Office of Research and Development (ORD) resulted in the EPA iron and steel R&D being combined into a multi-media program. This was accomplished by bringing together, at Research Triangle Park, North Carolina, ongoing iron and steel wastewater activities from ORD groups at Grosse Ile, Michigan, and Edison, New Jersey, and combining these with the air media portion of the program already in place at Research Triangle Park.

Program Responsiveness

During the same time period as the 1975 reorganization the regulatory and enforcement offices were coming up to their full working strength and efficiency as a result of implementing the mandated programs within the "Air" and "Water" Acts. To do their work, the Office of Research and Development had to respond to information and data needs that were developing. The Office of Research and Development in EPA is much like the research arm of any organization. If it does not support the product line of the organization, which in the case of EPA consists of regulations and enforcement activities, much of its purpose for existing will disappear. As a consequence, the activities of EPA/IERL-RTP's Metallurgical Processes Branch in iron and steelmaking pollution control have been aligning themselves more with the mainstream activities within EPA. Providing support to the regulatory and enforcement activities within EPA simultaneously provides support to the iron and steel industry. This statement is not inconsistent. Even though their motivations may differ, both EPA and the industry desire to achieve the required level of pollution control at the lowest cost.

Program Budgets

From Fiscal Year 76 through FY 80, which started October 1, 1979, EPA's consolidated multi-media iron and steel R&D program has had the following yearly budgets.

Fiscal Year	Air ($1,000's)	Water ($1,000's)	Solid Waste ($1,000's)
76	565	150	
77	468	442	
78	574	820	100
79	559	786	
80	340	530	200

Included in the above listing is funding from EPA's base industrial program plus some funds from the program offices for tasks specific to their needs. The FY 80 funding, as shown, is not complete. There will be additional funds to mount a program in recycle/reuse of waste water for the iron and steel industry and for projects to assist the program offices.

Environmental Assessments

Up to 1975 the work that had been done under the program was primarily concerned with pollution abatement technology development for a relatively few conventional pollutants. However there were mounting concerns that there could be other more hazardous pollutants being discharged from industrial and energy sources to air, water, and land receptors. This has led to the concept of a comprehensive characterization (called an environmental assessment) of all materials released to the environment by a source. Approximately one-third of our budget since Fiscal Year 76 has been for environmental assessments. In general an environmental assessment contains the following components.

1. An evaluation of the physical, chemical, and biological characteristics of all input and output streams associated with a process

2. Predictions of the potential effects of those streams on the environment

3. Prioritization of those streams relative to their individual hazard potential

4. Identification of any necessary pollution control technology.

Such an assessment is complex and technically difficult. The sampling program must be more extensive than a program acquiring data for process engineering type activities. Additional complexities are introduced by the necessity for detecting all materials, posing potential environmental hazard, above some minimum level of concern.

As would be expected, undertaking a comprehensive and all-encompassing environmental assessment of an industry or process would be expensive. To minimize costs, a phased or sequential approach is usually used in which the assessment proceeds to increasingly more specific and complex sampling and analysis, once the need and direction are established by a preliminary stage.

Three phases or sequences of environmental assessment have been developed. These in generalized form are:

Level 1 utilizes semiquantitative sampling and analysis procedures that yield final analytical results accurate to within a factor of 3 of the sample. Level 1 is designed to (a) provide preliminary environmental assessment data, (b) identify problem areas, and (c) formulate the data needed for the prioritization of energy and industrial processes, streams within a process, components within a stream, and classes of materials for further consideration in the overall assessment.

Level 2 is focused by Level 1 results and is designed to provide additional information that will confirm and expand the information gathered in Level 1. This information is used to define control technology needs, and may, in some cases, give the probable or exact cause of a given problem.

Level 3 involves monitoring the specific problems identified in Level 2 so that the critical components in a stream can be determined exactly as a function of time and process variation for control device development and evaluation.

Technology Development and Demonstration

Considering the low level of funding that was available compared to the high capital intensiveness of the industry and its processes, projects that were undertaken had to be judiciously chosen so as to provide maximum cost effectiveness. Two techniques used when possible, for development and demonstration projects, were cost sharing with the industry and by what could be called multi-use projects.

A major project of the cost shared type is the one to develop improved coke oven door seals, being done at Battelle Memorial Institute, in which the industry through the AISI has paid half the cost and EPA the other half. By this type of arrangement on projects that are identified as simultaneously being of high priority to both government and the industry, each of the two groups - EPA and industry - achieves greater cost-effectiveness for its available funding.

An example of a multi-use project is the mobile waste water treatment system which has been constructed and is operating at various iron and steel plants. The system, rated at 5 gallons per minute, consists of two separate wastewater treatment trains, one physical/chemical and the other biological, and has been operating on coke plant and blast furnace scrubber wastewaters. Operation of the system has not only been providing EPA with information and data that it vitally needs but is also providing good quality pilot plant data to the host plants to enable them to control their waste streams. Ultimately if the need exists the system might be used on other iron and steel industry wastewater streams.

From the two major projects which were just described, the projects range down in size. Included are engineering evaluations and technology development and studies.

Some of the smaller projects in the p ogram are in the form of grants to various universities to conduct applied research. This portion of our program, which is currently in its fourth year, is supported by about 10 percent of our budget. The majority of the projects in this group are cofunded with the AISI. Projects such as these will hopefully provide the advanced technology that will be needed for the future years. Cofunding of these projects with the industry enables us to fund more of these projects while also enhancing communication on pollution abatement technology needs with industry and the academic community.

Foreign Technology Evaluation

A vital portion of the iron and steel program is the identification and evaluation of pollution control technology used at foreign iron and steel plants. The objective is to ultimately show how the technology could be applied to plants in the domestic industry. If a domestic plant elects to use one of these technologies, it would, of course, have to do so under the business arrangements that are normal for such technology transfer.

There are currently two projects underway to evaluate foreign pollution control technology. The first is evaluating secondary emission control for the basic oxygen process. Included are emissions from charging and tapping, desulfurization, reladling, and deslagging. Preliminary evaluations are being made of plants in Western Europe and Japan. After completion of the evaluation, and with permission of the plant owners, sampling will be undertaken at selected plants which appear to have the most efficient control technology. Generalized engineering to show how this technology can be applied to the domestic industry is also included. The second foreign pollution control technology evaluation is concerned with wastewater treatment. Consideration is being given to coke-plant and blast-furnace top gas scrubber wastewater treatment and also to recycle/reuse. Visits have been made to Western Europe, Japan, Taiwan, and Australia. Visits have also been made to arid region plants in Mexico, South America, and South Africa to learn how they achieve high levels of recycle/reuse.

Another program concerned with foreign technology is the Ferrous Metallurgy Project under the US/USSR Environmental Agreement which has been the source of information on pollution control technology within the Soviet Union. The Soviet Union is now the largest producer of steel in the world, followed by the US and Japan.

Under the US/USSR program pollution control technology at a number of Soviet iron and steel plants and institutes have been evaluated by mixed teams of EPA and industry personnel. About 26 tonnes of dry quenched coke samples were obtained from the Soviets, distributed to several iron and steel companies, and subjected to a number of tests. The results were of interest to both the Government and the Industry.

The US/USSR Ferrous Metallurgy Project has now advanced to the cooperative phase. Projects have been identified and are underway on coke oven door seals and wastewater treatment. Status reports will be made as the projects proceed.

Under the foreign pollution control technology evaluation portion of the iron and steel program, unique technology applications have been discovered. It is essential that these applications be investigated and brought to the attention of both EPA and the iron and steel industry. It is expected that this work will be continued and even expanded where the opportunity presents itself.

Technology Transfer

The preceding description of the EPA research and development program for iron and steel presents a brief history of the program, its budget, responsibilities, and projects. The principal output of all these activities is technical information gathered on industry emissions and discharges and their control. Technology transfer is the very important final step of putting this information in the hands of the user.

Three types of technology transfers are practiced - reports, the EPA Ferrous Metallurgical Processes Review, and symposiums.

At the conclusion of our projects, final reports are issued detailing the results and conclusions, and also explaining the work that was done leading up to them. These final reports provide the basic documentation on a project.

Recently we put out our first issue of the EPA Ferrous Metallurgical Processes Review. This will be continued with approximately four issues per year, and will provide brief discussions of the work that is being done by us.

Finally we are sponsoring this, our first iron and steel pollution abatement symposium. Symposiums are an effective means for achieving technology transfer if the papers presented are carefully chosen. It has been felt that a need exists for a symposium dedicated to pollution abatement in the iron and steel industry. If there is sufficient interest, these symposiums will be continued and even expanded.

Table 1 IRON AND STEEL AIR PROJECTS UNDERTAKEN PRIOR TO FY 76

Cokemaking

Evaluation of Process Alternatives to Improve Control of Air Pollution from Production of Coke, EPA Report No. APTD 1250 (NTIS No. PB 189 266), January 1970.

Coke Charging Pollution Control Demonstration, EPA-650/2-74-022 (NTIS No. PB 234 355), March 1974.

Coke Oven Charging Emission Control Test Program, EPA-650/2-74-062 (NTIS No. PB 237 628), July 1974.

Emission Testing and Evaluation of Ford/Koppers Coke Pushing Control System, EPA-600/2-77-187a (NTIS No. PB 273 812), September 1977.

Enclosed Coke Pushing and Quenching System Design Manual, EPA-650/2-73-028 (NTIS No. PB 226 418), September 1973.

Sampling and Analysis of Coke-Oven Door Emissions, EPA-600/2-77-213 (NTIS No. PB 276 485), October 1977.

Study of Concepts for Minimizing Emissions from Coke Oven Door Seals, EPA-650/2-75-064 (NTIS No. PB 245 580), July 1975.

Blast Furnace

Blast Furnace Cast House Emission Control Technology Assessment, EPA-600/2-77-231 (NTIS No. PB 276 999), November 1977.

Sinter Plant

Sinter Plant Windbox Recirculation System Demonstration: Phase 1. Engineering and Design, EPA-600/2-75-014 (NTIS PB 249 564), August 1975.

Steelmaking

Development of Technology for Controlling BOP Charging Emissions, EPA-600/2-77-218 (NTIS No. PB 277 011), October 1977.

Table 2 IRON AND STEEL WASTEWATER TREATMENT PROJECTS UNDERTAKEN PRIOR TO FY 76

Cokemaking

Research Study of Coal Preparation Plant and By-Product Coke Plant Effluents, EPA-660/2-74-050, (NTIS No. PB 252 950) April 1974.

Biological Removal of Carbon and Nitrogen Compounds from Coke Plant Wastes, EPA-R2-73-167, (NTIS No. PB 221 486) April 1973.

Blast Furnaces

Pollution Control of Blast-Furnace Plant Gas Scrubbers Through Recirculation, EPA-660/2-74-051 (NTIS No. PB 250 435) July 1974.

Finishing

Treatment of Wastewater/Waste Oil Mixtures, EPA Project No. 12010 EZV (NTIS No. PB 195 161) May 1970.

Closed Loop System for the Treatment of Waste Pickle Liquor, EPA-600/2-77-127 (NTIS No. PB 270 090), July 1977.

Countercurrent Rinsing on a High Speed Halogen Tinplating Line, EPA-600/2-77-191 (NTIS No. PB 272 590), September 1977.

Limestone Treatment of Rinse Waters from Hydrochloric Acid Pickling of Steel, EPA Project No. 12010 DUL, February 1971.

An Electromembrane Process for Regenerating Acid from Spent Pickle Liquor, EPA Project No. 12010 EQF, November 1970.

Sulfuric Acid and Ferrous Sulfate Recovery from Waste Pickle Liquor, EPA-660/2-73-032, (NTIS No. PB 233 112) January 1974.

General

Combined Steel Mill and Municipal Wastewaters Treatment, EPA Project No. 12010 DTQ, (NTIS No. PB 210 198) January 1971.

Water Pollution Control in the Carbon and Alloy Steel Industries; EPA-600/2-76-193 (NTIS No. PB 252 963), April 1976.

ENVIRONMENTAL R, D & D

IN THE IRON AND STEEL INDUSTRY

by

Earle F. Young, Jr.
Assistant Vice President,
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at

EPA Symposium on
Iron and Steel Pollution Abatement Technology

October 30, 1979

It has been said in a number of places, and particularly in some government reports, that the iron and steel industry spends very, very little on research and development, and particularly on R&D in the environmental area. It is my hope today to refute that statement. I believe that it comes from a lack of understanding of the real nature of the technical problems of environmental control in the steel industry, and of the scientific, engineering, and technical work required to solve those problems.

My topic today, Environmental Research, Development, and Demonstration in the Iron and Steel Industry, is so broad that a major problem was deciding what approach to take. Should I make it a personal talk? Should I talk about AISI applied research through the years? Should I talk about AISI supported research in universities? Should I talk about research activities in company laboratories? Should I talk about research outside the steel industry itself, by the equipment manufacturers and vendors? Or should I concentrate on what is perhaps the most difficult and demanding aspect, the development of prototype units in the field? Looking at that list, I decided the right answer was "All of the above."

I'd like to start with a little personal account. I started in the steel industry back in 1956. Within the first year, I was involved in two major assignments which can properly be classed as research and development in the environmental aspects of the iron and steel industry. One of these was for my company, looking for a new process for the removal of phenolic compounds from coke plant wastes. This research was completed several years later and culminated in the development of the J&L solvent extraction dephenolization process. Initial laboratory studies of solubilities, equilibria, and basic data of that sort were followed by pilot plant work on new types of equipment, then design and installation of a plant, and then an extended period of break-in and modification, which ultimately resulted in what was, I believe, the best dephenolization process then available.

The second assignment, again back in 1956, was working with the Steel Industry Advisory Committee of ORSANCO. This group was attempting to evaluate all the technology then being proposed from a number of different sources as means of recovery and regeneration of sulfuric acid waste pickle liquor. That study, which was completed about a year later, came to the conclusion that, while in the laboratory one could regenerate waste pickle liquor, none of the processes then available was economically viable. Shortly therafter, a consortium of steel companies invested what was then a lot of money in a pilot plant to test a new technology, the Blaw-Knox Ruthner process. That work confirmed our conclusion: "Waste pickle is a lousy raw material for sulfuric acid." That conclusion has held up pretty much correct over 20-some years.

I think that's enough of the personal story to indicate (1) that the steel industry has been doing research in the environmental area for a long time, and (2) that I've been familiar with this work for a long time.

The American Iron and Steel Institute is a trade organization which represents some 63 domestic steel companies accounting for over 93% of the steel production of the United States. Since 1938, for over 40 years, the AISI has sustained the Water Resources Fellowship at Mellon Institute, now properly known as Mellon Institute of Carnegie-Mellon University. For this entire period, the resources of this fellowship have been directed at basic and applied investigation of pollution problems of the iron and steel industry. The fellowship has resulted in a great deal of fine technical work and many technical publications. The first published paper, "Industrial Stream Pollution Problems and Their Solution," by Richard D. Hoak appeared in Chemical Industries in August 1941. The most recent paper published by the fellowship is "Evaluation of EPA Recommended Treatment and Control Technology for Blast Furnace Wastewater" by S. C. Caruso and George M. Wong-Chong, published by the American Society of Civil Engineers in April 1978. The fellowship has built and maintained one of the finest water analytical laboratories in the world. This has been devoted to development of many of the analytical procedures now in use throughout the industry and by the EPA, as well as to analysis of special samples for the industry and providing a referee analytical capability for the industry. The fellowship has investigated a wide variety of processes, looking both at the chemistry and the process engineering of industry waste treatment. The work of this fellowship continues under the direction of AISI's Technical Committee on Environmental Quality Control. That same Committee has also sponsored a number of other studies, ranging from biological treatment of coke plant wastes to gas evolution during slag cooling.

AISI also has a Committee on General Research which has for many years been supporting basic and fundamental research programs at universities. In the past decade, this Committee has supported 20 environmental research projects, ranging from studies of reaction kinetics and mechanisms through exploration of new chemical and physical processes for pollution abatement. We are proud to note that EPA considers these projects to be of sufficient value that EPA has joined us in the funding of about half of these projects in our current program.

A significant proportion of the research activities in the member steel companies is also devoted to environmental work. Based on a very informal survey, I find about 15% of the total research expenditures in the steel companies is applied to pollution abatement projects. The scope of these is very wide-ranging and would have to be reported by the companies themselves. Several of the papers being presented later in this symposium by steel company representatives will demonstrate the types of work going on.

In addition to the work done within the steel industry itself, the industry has been offered and in many cases has taken advantage of extensive research and development by equipment manufacturers and by engineering contractors. The manufacture and sale of pollution abatement equipment is a very competitive field. Improved technology is one way to beat your competition. While I haven't seen any better mousetraps, I have seen improved precipitators, scrubbers, clarifiers, flocculators, filters, you name it. The R&D that goes into improved equipment is incorporated in the steel plant facilities and, I assure you, it's paid for by the steel companies in the price of the equipment they buy.

I've talked so far about what you generally think of as research and development, and the many sources of the basic technology for environmental cleanup of the steel industry. But there is another aspect of the development of practicable, workable, plant-scale technology which far exceeds all of the above in cost to the industry, and yet which is often neglected in consideration of industrial R&D. It's called "making things work."

The steel industry is big. We handle about 300 million tons of raw materials every year. From this we produce about 100 million tons of finished steel products, and, remember, steel sells for about 20 cents a pound. The very size of the operations involved in the steel industry is such that many units that are installed in the industry represent an extrapolation in size from anything built and installed in other industries. This presents unique problems.

We work at extreme conditions. The large tonnages of materials utilized in the industry are heated at temperatures up to the range of 3000°F in the smelting and refining operations. These extreme conditions impose unique problems.

We work not with pure substances, but with very complex mixtures of natural materials. The best example, of course, is coal, which is broken down in the coking process to a huge variety of compounds ranging from the simple hydrogen and carbon monoxide through the aromatics, benzene, toulene, and xylene, and on into the more complex tars and tar acids. This results in purification problems much more complex than they appear on the surface.

And our operations are cyclic. This is exemplified by the coke ovens, where coal is charged to the ovens and 17 hours later coke is pushed from those same over . Or consider a basic oxygen steel furnace, where in a period less than an hour the vessel is charged with scrap, then hot metal, then blown with oxygen to achieve the refining reactions necessary to make steel, and then tapped to get this molten steel from the furnace. Gas evolution varies from essentially none at room temperature to hundreds of thousands of CFM at 3000+ degrees, and back to nothing. This means that steady-state design parameters just don't work for our systems.

Because of the range and complexity and cyclic nature of the operating conditions that are encountered in steel mills, it turns out that the technology required for effective working plant systems goes far beyond the technological principles that can be developed in laboratory and pilot plant. Almost every installation in the steel industry is a prototype, and the biggest and most complex technical jobs are making those prototypes work in the big, hot, impure, cyclically varying atmosphere of the steel industry.

I'd like to illustrate this with some examples.

One relatively simple example was the installation of deep bed pressure filters for treatment of hot strip mill effluents at a member company. A large installation was made based on good engineering design and vendors' recommendations. But let me read you a few sections of the initial report presented by the company which installed this system. "The week of December 28th, the filters went into 24-hour operation. The week of January 4th effluent quality began to deteriorate." "The plant could not be kept in service for more than two or three days without going down for an extended backwash; the vendors specified backwash cycle could not be used to properly flush the tanks." "Finding the proper combination of flocculant and alum and the proper injection procedure took months of experimentation." "Other unforeseen problems . . . ." I could go on, but I think I've made my point. The start-up of a prototype system in a steel mill proved complex, vexatious, and expensive.

Another steel company installed a complex system for treatment of wastewaters from its coke plant. That system included two distillation towers for ammonia removal. To give you an idea of the scale of operation, the larger tower is 127 feet tall. A paper presented by that company said, "The total ammonia recovery system had never been operated before and no operating information was available. This facility is a test unit for subsequent plants." The biological treatment section of this plant is larger and more complex than most municipal plants. In spite of a large electronic control system, the operation of this plant boils down to, and again I quote from the operators of the plant, "This is mostly an operator judgment situation where a visual observation of the color, smell and consistency of the froth dictate whether changes in operation are required." This system cost $27 million to install, yet it was truly a prototype and it took years and millions of dollars to make it operate.

In the steelmaking area, the emissions from the steelmaking processes are a long-recognized problem and one that the industry has largely solved. Today we have installations of electrostatic precipitators, wet scrubbers, and bag houses. I can tell a number of tales of the complexities of the development work required to make these systems operable. I could tell of systems which were put in after very careful design and found not to do the job they were designed to do. They had to be replaced or upgraded. But this is an area where, I think, we now have mature technology. We do know how to install equipment to control the process emissions from steelmaking.

Today, however, the emphasis is changing from control of process emissions to control of fugitives. After the controls were developed and installed on the main emissions came a recognition that other operations -- the charging of the furnace, the tapping of the furnace, the handling of the materials into the furnace -- also caused emissions, what we call process fugitives. Today a number of systems are being installed attempting to control charging and tapping emissions. One member company installed a canopy hood system at a cost of over $2 million attempting to control these. And just last year they added to that system a second system at a cost of $4.6 million to control charging and tapping emissions. This was the first retrofit of its kind installed anywhere in the country. Reports are that it works very well, although there are still some emissions from the building.

But installations of this type are pioneering, prototype installations, and their development represents a major expense which I feel properly is classified as part of the R, D & D effort of the industry, although it does not show up as a research expense.

Turning to the coking process, which presents the major technical problems of the industry today, I'd like to consider briefly two operations, charging and pushing. Several years ago, AISI and EPA jointly sponsored a million dollar research program attempting to develop a charging system. The program was not a complete success, but some of the mechanical developments attempted in that operation are included in today's stage charging operations. Stage charging is a simple process in concept: the coal is charged to the ovens in such a way that gasses drawn into the by-product gas system carry with them all the particulate emissions. It's simple in concept and theory, but making it work in the plants has involved equipment changes, operating changes, and personnel changes. These are time consuming and expensive, and they have succeeded. Charges for this time and expense don't show up as R&D, but truly represent development necessary to clean up steel mills.

The final operation I'd like to talk about is the control of coke oven pushing. When coke is pushed from ovens, there are some emissions. At times, there are copious, black, burning, ugly emissions. In recent years, the industry has been working hard on the development of systems for the control of these emissions. In principle, it's very simple. You capture the emissions in a stream of air, then you pass that stream of air through a dust collector and isolate the emissions. In practice, to achieve this simple end is a very difficult task. It can be investigated only with full-scale installations. A wide variety of systems has been built on an experimental basis, and yet there is none today that is universally considered 100% reliable and completely satisfactory from the viewpoint of performance. Nonetheless, 65 installations of a possible 96 installations in the industry will have some type of pushing emission control facility attempting to operate by the end of this year. At an average cost of over $4 million per installation, this represents an investment of well over a quarter of a billion dollars on unproven technology. That, I think, is the outstanding example of research, development, and demonstration in the iron and steel industry.

I hope this brief presentation has been enough to convince you, as I am convinced, that the steel industry's major investment in environmental research, development, and demonstration has been an important part in the transition from the steel plant of yesterday to the steel plant of today and tomorrow.

Session 1: AIR POLLUTION ABATEMENT

Chairman: Joseph W. Kunz, Acting Chief
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AIR POLLUTION EMISSION STANDARDS

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Thank you, Mr. Chairman.

I appreciate the opportunity to review with you the regulatory actions EPA is considering for the iron and steel industry.

In the half-hour allotted to this discussion, I plan to review for you the status of each federal regulation or potential regulation relating to the steel industry. My summary will be restricted to about 20 minutes to allow time for your questions and comments.

We are currently working in three areas:

(1) Review of existing standards. The Clean Air Act Amendments (CAA) of 1977 require EPA to review and revise where appropriate all New Source Performance Standards (NSPS) every 4 years.

(2) New regulations are being considered under Section 112 because the pollutions are either declared hazardous or potentially hazardous. In this regards I am referring specifically to benzene and polycyclic organic materials (POM).

(3) Finally, additional regulations that will regulate new or modified sources (coke-oven charging, top side and door leaks, by-product plants) but not existing sources. These regulations are required by the CAA amendments of August 1977.

Under the first category, review of existing standards, two sources in the steel industry have been regulated by new source performance standards for some time. These are basic oxygen and electric arc furnaces. Regulations controlling particulate emissions from BOF furnaces were promulgated on March 8, 1974, and required control of only the primary emissions to a level of 0.02 grains per dry standard cubic foot. Opacity regulations were not promulgated at that time because our data were considered insufficient and inconsistent. Secondary or fugitive emissions were also not regulated. In March, 1977, after the collection of additional data, opacity regulations were proposed for BOF furnaces under EPA's Method 9. These regulations were promulgated in April 1978 limiting the opacity to 10 percent with the provision that opacity as high as 20 percent may occur once per steel-production cycle.

Immediately following this promulgation, legal action was taken by two environmental groups, NRDC and GASP, who protested that EPA should also regulate fugitive emissions. We attempted to resolve this litigation out of court by discussing this with the two environmental groups. EPA agreed that the fugitive emissions from BOF furnaces are significant but that we did not include these sources in the initial regulations because there was no demonstrated technology at that time upon which to base a regulation. EPA did agree that there was technology now being developed to control BOF fugitive emissions, both in this country and in Europe and we proposed a schedule to the environmental groups for the collection of this data and the preparation of the regulation. However, we were unable to agree with the environmental groups that our schedule calling for initiating the engineering work in October 1979 with standard proposal in April 1981, was reasonable. We were unsuccessful in convincing the environmental group that the schedule could not be shortened because BOF fugitive emissions are difficult to test. In fact, new test methods must be developed. Briefs were filed with the court and oral arguments were heard on September 20, 1979. We are awaiting decision from the court concerning our proposal.

While this litigation was underway, we continued our review of the existing BOF NSPS as required by the CAA and have published our conclusions. Briefly these are the following:

1. The best demonstrated system of emission control at the time the standard for primary emissions was established has not changed in the past five years. These technologies control emissions to a level consistent with the current standards. Therefore, revision of the existing standard is not required if only primary emissions are to be controlled.

2. The ambiguities in the present standard concerning the definition of a BOF furnace and the operating cycle during compliance testing need to be clarified and a project to do so has been initiated.

3. Secondary or fugitive emissions from BOF furnaces represent a major air pollution emission source. EPA, therefore, intends to initiate a project to revise the existing standard of performance to cover these fugitive emissions. This project is scheduled to being in October 1979, and lead to a proposal 20 months later.

The second existing standard which has undergone review is electric arc furnaces. The new source performance standards to control particulate emissions from electric arc furnaces was proposed in October of 1974 and promulgated in September 1975. This standard dealt only with particulate emissions from the furnace during normal operations, restricting them to 0.005 grains per dscf.

Since the NSPS was promulgated in September of 1975, five new installations subject to the NSPS have been completed. Although only one official NSPS compliance test has been carried out since promulgation of the new source performance standard, some unofficial test data indicate that certain new furnaces are well below the NSPS for particulates and visible emissions. However, the effectiveness of pick-up systems for process and fugitive emissions has greatly improved. Plants are now using total enclosure in conjunction with hoods and air curtains, to capture melt downs, charging, tapping, and slagging. It has been recommended therefore that the standard be modified to give consideration to these new capture techniques. This recommdndation is made in spite of the fact that fabric filters, the primary method of emission control when the original standard was promulgated, are still considered the best control technology. In addition, it is recommended that argon-oxygen decarbonization furnaces be included in the revised EAF standard since they are often found in EAF shops and utilize common control systems. We anticipate approval of our recommendation by the EPA Administrator and publication of our findings for your comment late this year. Schedules for actual revision of the regulation will be developed following a review of the public comments.

The second area of EPA regulation of steel mill emissions is under Section 112 which deals with hazardous pollutants.

Section 122 of the Clean Air Act specifically requires the Administrator of the Environmental Protection Agency to make a regulatory decision regarding control of atmospheric emissions of polycyclic organic matter (POM) on the basis of a health risk assessment of these emissions conducted by EPA and supported by similar assessment of coke-oven emissions. The Administrator is considering POM as a hazardous air pollutant under Section 112 of the Clean Air Act. In anticipation of this, EPA is in the process of developing and collecting data upon which regulations limiting POM emissions from coke-oven production facilities can be based. We have used data from epidemiological studies and ambient monitoring to estimate the health risk of POM emissions from coke plants. For our health risk calculations we have taken into consideration the improved emission control at coke plants resulting from implementation of State regulations, consent agreements, Occupational Safety and Health Administration regulations, and industry initiatives.

The regulations we are considering would, as a minimum, require emissions control to levels that are attainable with best available control technology as defined by EPA's recently proposed cancer policy. The types of controls upon which the standard would be based will vary among the sources within the coke plant, but may include revised operating and maintenance procedures as well as modifications to equipment and installation of control devices.

Health assessment documents are now being prepared. It will be necessary to obtain concurrence from the Administrator's Science Advisory Board on the listing of POM under Section 112 of the Clean Air Act as a hazardous air pollutant. Current schedules call for listing POM in March of 1980 with public hearings to follow. In anticipation of this designation, we are looking at sources of POM which we will be required to regulate in response to the listing of POM as a hazardous pollutant. The initial sources involved are wet coal charging, topside leaks, and the door leaks which are all part of coke making. The technical package for this regulation will be available next summer, with a proposal anticipated in about a year.

Since this action is under the hazardous pollutant section of the CAA, any regulation will apply to both new and existing sources.

A second coke-oven source which will probably be regulated under Section 112 of the Act is dry coal charging, more commonly referred to as coal preheating. Our preliminary data indicates that the emissions contain polycyclic organic matter (POM) but the technical work to support a regulation has just been initiated. Any regulation will be over a year away.

Another pollutant which may be regulated as a hazardous pollutant is benzene. Benzene emissions were officially listed by EPA as a hazardous pollutant under Section 112 of the Act on June 8, 1977, and regulatory packages are being prepared for the major benzene emitting sources.

Our highest priority of sources emitting benzene are:

1. Maleic anhydride production.
2. Coke by-product plants.
3. Benzene storage and handling.
4. Gasoline marketing.

With regard to the by-product plants, we initiated the preliminary analysis of the process streams to determine which streams contain the major quantities of benzene. This was an attempt to determine the primary sources of benzene emissions from a coke oven by-product plant. This analytical work has proven to be very difficult, and I anticipate some delay in categorizing the sources which will require control. In spite of these delays, I anticipate having a technical package for review by an internal EPA working group in mid-1980, and, of course, we will make it available to the industry for your comment at that time.

The final area which we should cover is the development of standards of performance for new or modified sources for which there is no existing NSPS.

During the 1977 hearings on the Clean Air Act, Congress received testimony on the need for more rapid development of new source performance standards. There was concern that not all sources which had the potential to endanger public health or welfare were controlled by NSPS and that the potential existed for environmental blackmail from source categories not subject to NSPS. These concerns were reflected in the Clean Air Act amendments of 1977, specifically in 111(f). We were required to use the three criteria listed by Congress: (a) the quantity of emissions, (b) the extent to which each pollutant endangers public health or welfare,

(c) and the mobility and competitive nature of the sources, to prioritize all sources which should be subject to new source performance standards. This has been accomplished, and EPA has undertaken a program to promulgate new source performance standards for source categories on this priority list by August 1982. Development of standards has already been initiated for nearly two-thirds of the source categories on the priority list. Work on the remaining source categories will be initiated within the next six months. The following will be a brief summary of the steel industry sources to be covered:

1. Coke-Oven Battery Stacks. Source testing was completed at Kaiser Steel in Fontana, California, during September. Benzene soluable organics, particulates and benz-a-pyrene were measured. We expect the technical report to be completed in early 1980. Proposal is scheduled for about October 1980. Data confirms our decision to develop NSPS rather than NESHAP for battery stacks.

2. Wet Coke Quenching. This source was originally thought to be a high emitter of POM. However, data now available indicate this is not the case and it is now considered a candidate for NSPS for particulate rather than NESHAP. As you will see later in the program, testing is complicated and expensive. Our current thinking is that clean water and good design baffles will be the approved technology. However, we are watching closely a source test being conducted this week at Lone Star Steel. Our schedule is not clear but a proposed regulation is at least a year away.

3. Sinter Plants. This has just been initiated as a Section 111 NSPS project.

4. Desulfurization of Coke Oven Gas. EPA will begin engineering work in February 1980.

5. Coke-oven Pushing. We do not currently have a schedule for coke pushing. It is not considered a POM source but could be a particulate source.

INNOVATIONS AND IMPROVEMENTS OF THE ORE SINTERING PROCESS FOR AIR POLLUTION CONTROL

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Presentation: Symposium on Iron and Steel
Pollution Abatement Technology
U. S. Environmental Protection Agency
Chicago, Illinois
October 30 - November 1, 1979

INNOVATIONS AND IMPROVEMENTS OF THE ORE SINTERING PROCESS FOR AIR POLLUTION CONTROL

Thomas E. Ban

The McDowell-Wellman Company

ABSTRACT

An improved sintering process for agglomerating ores has been developed at the Dwight-Lloyd Research Laboratories. This embodies strand cooling with hot and cold recycle draft streams. The new process minimizes draft exhaust quantities, oxidizes entrained hydrocarbons, refilters solid particulates, and conditions the final sinter plant exhaust for ultimate cleaning.

INNOVATIONS AND IMPROVEMENTS OF THE ORE SINTERING PROCESS FOR AIR POLLUTION CONTROL

INTRODUCTION

The continuous sintering process for agglomerating ores is perhaps the highest capacity processing system in the metallurgical industries. On a worldwide basis the production of sinter in ferrous metallurgy exceeds 500 million tons per year and the nonferrous and non-metallic industries produce about 40 million tons per year. The large individual Dwight-Lloyd machines consume more than 15,000 tons per day of raw materials and have exhausts of combustion draft which exceed 1,000,000 CFM.

In extractive metallurgical practices sintering is used to beneficiate ores through a high temperature agglomeration process. This makes a "furnaceable" product from raw ore which would otherwise have substantial penalties because of fines, nonuniform size consist, poor handling characteristics, and detrimental chemistry. Additionally, sintering is used to recycle plant waste dusts and to pre-blend and pre-calcine fluxstone as a constituent with ore charge to provide a self-fluxing or superfluxed sinter.

Beneficiation is an all encompassing term to cover the improvement of the physical and chemical properties of an ore by lowering the cost requirements for smelting. Conversion of ores, recycle fines and fluxes into beneficiated charge of sinter product is noted by the following factors.

1. The fines are agglomerated into hardened semi-fused and enlarged particles which are porous and durable for gas-solid smelting reactions.
2. The raw materials are dried and calcined for removal of sulfides and hydrocarbons as well as carbonates, sulfates, and hydrates which cause endothermal smelting reactions.
3. Undesirable constituents as volatiles and sublimates are removed from the product by high temperature reactions of sintering.

Sinter product is characterized as hardened, cellular masses which are specifically crushed and graded for smelting furnace operations, i.e., ideally, -1"+1/4" structure resembling "popcorn" in shape and size.

PRINCIPLES

The sintering process is carried out by incipient fusion of bedded particles in the quiescent state. Combustion of solid fuel dispersed within the bed and induced draft are used to sustain the sintering phenomena. In continuous practices raw materials such as ore fines, fluxes, fuels and recycle return fines are proportioned, blended and tumbled with moisture to create a nodular textured burden as a ribbon of porous charge for a series of traveling grates. The leveled charge supported on moving grates is surface ignited by flame ignition and a combustion draft is induced through the bed by suction fans which perpetuate a frontal firing wave downward through the charge as it is transported horizontally by the traveling grates. This gives rise to an inclined firing plane throughout the moving sinter bed as illustrated in Figure 1. The high temperature firing zone causes incipient fusion at the solidus temperature of the blended raw materials. In the case of iron ore sintering this peaks at about 2500 °F.

The mechanics of sintering is typified as a series of periodic thermal gradients or a firing wave front advancing through the charge as exemplified in Figure 2 which illustrates the gradients at initiation of sintering and 25%, 50%, 75% and completion. The peak temperature of the wave is the firing zone and it is preceded downstream by the lower temperature calcining and drying zones respectively as the wave advances toward the unreacted charge. A cooling zone is upstream of the firing zone and it serves to transfer and recuperate sensible heat for the draft of combustion. Figure 1 further illustrates the specific zones within the moving sinter bed as unreacted charge is converted into cooled sinter through coincidental combustion, calcination and vitrification reactions.

The quiescent state of the sinter bed charge and the filter bed nature of wet packed nodules in the lower layers are features which minimize entrainment of solids in the draft stream. Sintering is remarkably efficient in this respect. It is shown that less than 0.1% of the charged materials become air entrained or stripped from the bed despite the severe temperature changes, high velocities of evacuated draft and use of raw materials comprised of 100% minus 200 mesh particles. Contrarily, sintering gives rise to emissions because one of its functions is to pre-remove the deleterious volatile constituents from the ore. The high temperature firing phenomena cause constituents such as alkalies, chlorides, heavy metal salts, and other sublimates to fume from the firing zone and be entrained in the draft stream. Also, higher draft temperatures which precede and follow the drying front cause volatilization of inherent hydrocarbonaceous materials within the sinter burden.

Recycle steel plant materials such as flue dust and sludge contain high quantities of salts and sublimates because the original plant dusts nucleate their precipitation. These dusts also contain high percentages of condensables such as hydrocarbons. Other prominent sources of condensables as potential particulates are the lubricants inherent with recycle mill scales, flotation reagents of ores and the volatile matter constituents of the coke breeze and other types of solid carbonaceous sinter fuels.

SINTERING PRACTICES

A generalized flowsheet as a sinter plant layout is shown in Figure 3 which illustrates a conventional plant for converting iron ore fines, miscellaneous plant dusts, and limestone into self-fluxing sinter. Raw materials of a wide variety of physical characteristics are ordinarily delivered to rail, truck or yard hoppers for admission to the sinter plant. These materials consist of (1) several varieties of iron ore fines as minus 3/8 in. screenings in the damp natural state, (2) miscellaneous steel plant recycle materials such as dry or conditioned blast furnace flue dust, moist sludge and mill scale, (3) fine limestone, and (4) ground coke breeze for sinter fuel. After charging these into the plant they are transferred by belt conveyers to separate day bins which surge and proportion the raw materials. Table feeders or large belt feeders are used to withdraw materials as controlled by belt scales to a collecting conveyer and withdrawal rates are pre-designed to produce controlled carbon input of approximately 4%

of the charge. Limestone is controlled to make the required basicity ratio with gangue constituents.

A nodulizing operation is used to blend and prepare the raw materials as a uniform and permeable charge with a nodular texture. While the raw materials are in transit to the nodulizing operations they accumulate recycle fines from dust collectors and hot and cold sinter screening operations which supply sinter returns. The composite blend is nodulized with moisture in rotary drums and nodules are charged to the Dwight-Lloyd® traveling grate. In many cases a recycle hearth layer comprised of 3/4x1/4-in. sinter returns is applied as an initial 1½-in. layer directly upon the grates to serve as a charge filter, heat sink and a parting plane for facilitating the discharging. Raw nodulized sinter machine charge is applied directly on the hearth layer and it is leveled by a strike-off gate to an even 12- to 18-in. layer which passes directly beneath an ignition furnace. Open flame for about 60 to 90 seconds duration ignites the surface of the bed and this initiates the sintering reactions which are maintained by a continual downdraft as induced by a sintering fan. Dust collection equipment is used downstream of the fan and the exhaust is directed to a stack. Sinter production is controlled to terminate when the fired line reaches the grates at the discharge end. A consolidated sinter cake which is relatively cool in the upper layers and hot, semi-fused near the bottom layers is discharged as a mass the approximate size of the sintering machine pallet. In large installations the cake is approximately 10-ft. wide by 4-ft. long by 12-in. thick. Rotary breakers and stationary grizzlies serve as primary crushers for the cake and a hot screen is used for immediate rejection and recirculation of hot sinter returns.

The gravity flow arrangement allows the broken, hot sinter to be continuously applied to a circular traveling grate and forced draft fans are used to air cool product by convection. Cooled product is then transferred to a final screening station for recovery of cold returns, hearth layer, and final disposition of the sinter product to storage piles. In the more modern sinter plants the final sinter product is carefully crushed and graded to the preferred size of about 1x1/4-in. sizes and further sinter returns are generated by this operation.

The conventional sinter plant and sintering system have disadvantages which impose high capital and high processing costs as well as environmental problems. Some of these are listed as follows:

1. The belt transfer of unconditioned, dusty raw materials and returns on conveyer systems creates high quantities of in-plant airborne dusts.
2. The gravity transfer of hot sinter through the discharge end - hot screening - cooling series imposes capital and operating expenses inherent with multi-story operations.
3. The hot sinter discharge imposes expense for hot crushing, hot screening, and hot de-dusting because of excessive maintenance, downtime periods, and plant returns with lower sinter product qualities.
4. The separate sinter cooler machine as charged with a wide range of broken sinter sizes requires excessive draft exhaust and machinery because of parti-

cle segregation and nonuniform distribution of cooling media.

5. A very large volume of sinter machine exhaust as collected by windboxes along the machine necessitates extensive and massive air pollution control equipment for arresting fine entrained particulates.

Three prominent stack sources for sinter plant emissions can be noted in the flowsheet of Figure 3 and each of these are specifically identified in the following outline:

1. The main sinter machine exhaust

   This source contains all of the products from the high temperature sintering and combustion operations as composited from all windboxes along the sintering machine. The high temperature sintering phenomena cause entrainment of fine dusts, sublimates and condensable hydrocarbons. Table 1 presents some general compositions and characteristics of iron ore sintering stack emissions which ordinarily escape arrestment from low energy "cyclone" dust collectors.

2. Discharge end - screening exhaust

   This source of emissions is caused by unconsolidated particulate matter in the product which becomes entrained through dumping, crushing, and screening operations.

3. Cooler exhaust

   Emissions in the massive exhaust of cooling operations are largely caused by entrainment of unconsolidated particles in the product which are a result of screening inefficiencies and improper sintering operations.

IMPROVED SINTERING PROCESS

A new sintering process has been developed at the Dwight-Lloyd Research Laboratories which uses recycle draft with strand cooling principles for overcoming air pollution. A combination of cold recycle draft from initial windboxes and hot recycle from terminal windboxes re-uses sinter flue gases for the following purposes:

1. Settling partials of solid particulates within the wet nodular filter bed of the sinter charge.
2. Incinerating partials of entrained condensables and combustible gases
3. Diminishing the volumes of exhaust gases.
4. Conditioning exhaust gases for ultimate cleaning.

The elements of this new patented process have been proven within several continuous pilot plant sintering campaigns and currently the principles are being carried out in commercial design and operations. Essentials of the process are illustrated in Figure 4 which shows the draft flow arrangement with a sinter bed section on the Dwight-Lloyd traveling grate. The sintering is performed by terminating the fire line of combustion approximately midway within the third zone which completes the combustion and performs primary cooling. Terminal cooling is carried out in the fourth zone and the preheated air is recycled for initiating sintering immediately after ignition. The second and third zones use sequences of cold recycle draft and the final exhaust is vented from the third zone. Through this arrangement sintering is maintained with its flue gases containing H_2O, CO_2, and O_2, each within the range of about 8-16%. This media has been proven adequate if not beneficial for the maintenance of all sintering phenomena. Figure 4 illustrates the use of low energy inertial collectors such as cyclones for protection of the recycle blowers and two stages of cleaning preceding the final exhaust blower in the third zone. These stages are used to indicate sequences of ultimate incineration or quench stages followed by dry or scrubbed particulate removal. Table 2 provides some pilot plant data which compares sinter machine emissions of the conventional process with the improved process. From these data it is apparent that the emissions can be reduced by a factor of two to four through use of the Improved Sintering Process™. Because of the recirculatory draft system the CO_2 and H_2O contents of the draft stream increase two- to threefold and the exhaust draft temperatures increase from about 250 °F to 650 °F. The draft of the Improved Sintering Process is thereby conditioned with humidity and temperature for dry electrostatic precipitation. Also, the diminished volume enables a high velocity energy scrubber to be economically applied for arresting the diminished loading of both solid and condensable particulates for compliance of sinter plant environmental requirements.

BENEFICIAL ASPECTS

The adaptation of strand cooling principles of the sintering processes has finally been accepted in European iron ore practices wherein nine very large scale plants have been constructed since 1973 by Delattre-Levivier, licensee of the Dwight-Lloyd sintering process of the McDowell-Wellman Company(1).
Though pioneering efforts were carried out by Jones & Laughlin Steel Corporation during the early 1950's using strand cooling principles of the Dwight-Lloyd sintering process, at Benson mines, more than 25 years elapsed before it was accepted in the very large scale iron ore sinter plant construction(2,3). Strand cooling plant designs have shown capital and operating cost benefits over the conventional sinter plant design illustrated in Figure 1. These benefits have been attained principally because of the low profile plant construction, single machine utilization, and maintenance-fuel process savings.

Use of draft recycle has been practiced in pelletizing operations for converting fly ash and iron ore concentrate wherein the pellets were fired with solid fuel. Future developments of sintering utilizing the liquid sealed circular sintering Dwight-Lloyd machine will show further cost savings and low cost environmental control through the totally sealed features of the circular machine.

Comparison of the materials balance flowsheet for conventional sintering and the Improved Sintering Process are illustrated in Figure 5 which shows the marked diminution of exhaust volumes (4). In capsule, the Improved Sintering Process offers the following advantages over conventional sintering practices.

1. Quantity of total exhaust draft: 25-35% of that in conventional sintering practices.
2. Quantity of solid particulate materials in exhaust stream: 20-50% of that in conventional sintering practices.
3. Quantity of condensable particulates in exhaust stream:

15-45% of that in conventional
sintering practices.

Pilot plant experience from sintering iron ore with blast furnace flue dust and mill scale have shown organics as condensable hydrocarbon emissions to be lower than 0.03 gr./dry std. cu. ft. ahead of particulate arresting equipment. The foregoing improvements may meet compliance without extensive further cleaning of draft streams. However, if further cleaning is required it is more economically attained. This is apparent because of the volume diminution and conditioned nature of gases for further treatment by incineration, dry precipitation, or wet scrubber applications.

COMMERCIAL APPLICATIONS

After detailed pilot plant and engineering design work by McDowell-Wellman Company, the Jones & Laughlin Steel Corporation constructed a single pass cold recycle sintering system at their 6,000 tons/day Aliquippa iron ore sinter plant. The commercial data essentially verified the pilot plant test data which were used as bases of design for retrofit and which illustrated:

1. Maintenance of the high sinter rates despite the use of recycled flue gas as sintering media.
2. Considerable diminution of exhaust gas volumes.
3. Marked diminution of solid and condensable particulates.

A large pilot plant project was recently completed for Lone Star Steel Company using the Improved Sintering Process - Multipass Recycle and Strand Cooling. On the bases of very favorable results, Lone Star Steel Company is constructing a large scale sinter plant at their ore beneficiation facilities at Lone Star, Texas, which will use this new technology. As a result of separate field studies by Lone Star Steel Company, the Improved Sintering Process will embody a new design of the Lone Star Steel Company proprietary Hydro-Sonic® scrubber(5). This will operate within the depleted volume and depleted particulate exhaust stream of the sintering process. All test data confirmed that the Lone Star Steel Company sinter plant will economically and environmentally conform to the air pollution code requirements.

SUMMARY

Conventional sintering practices for agglomerating ores have high air pollution concerns because of massive total draft exhaust volumes containing fine solid fume and condensable particulates. These disadvantages can be overcome to a considerable extent by use of an Improved Sintering Process which uses recycle draft and strand cooling principles. This innovation combines the multiple machine applications of the conventional practices into a single Dwight-Lloyd sintering machine. The overall benefits are cost savings inherent with strand cooling and marked diminution of (1) draft exhaust, (2) solid particulates, and (3) condensable particulates.

On the basis of favorable continuous pilot plant operational data, the commercial applications have been committed and initiated.

LITERATURE CITED

1. Dorville, Robert, N. Meysson, J. Astier, J. A. Didier, 36th Ironmaking Proceedings, The Iron and Steel Society of AIME, Vol. 36 (Pittsburgh, April 1977).
2. Simon, Francois, Robert Nicholas, "No. 2 Sintering Plant at Sidmar," The Iron and Steel Engineer, July 1973.
3. Rowen, Harold, "Modern On-Strand Sinter Cooling," Society of Mining Engineers Fall Meeting, AIME, Pittsburgh, Pa. (September 1973).
4. Ban, Thomas, "An Improved Sintering Process to Overcome Environmental Problems in the Sinter Plants," Society of Mining Engineers Annual Meeting, AIME, (New York, N.Y., 1975).
5. Ewan, T. K., J. S. Master, "Fine Particle Scrubbing with Lone Star Hydro-Sonic Cleaners - The Coalescer," Second Symposium on Fine Particulate Scrubbing, sponsored by US-EPA, (New Orleans, La., May 1977).

TABLE 1
IRON ORE SINTER MACHINE EMISSIONS
GENERAL RANGE OF ANALYSES*

	Chemical Analyses %	Size Analyses Cum. % Retained	
Fe_2O_3	10-40	+40 Micron	10-50
SiO_2	2-8	+20 Micron	15-65
Al_2O_3	2-5	+10 Micron	20-80
CaO	7-15	+3 Micron	60-90
MgO	2-5	+1 Micron	90-95
K_2O	2-10	-1 Micron	5-10
Na_2O	1-6		
Cl^-	3-10		
$SO_4^=$	4-14		
Organics	10-40		

Grain Loading of Particulates:

Solids: 0.1 to 0.5 gr./dry std. cu. ft.
Condensables: 0.05 to 0.3 gr./dry std. cu. ft.

* Multiple source of information as general range data from six different plants after primary cleaning by cyclones.

TABLE 2
EMISSIONS MEASURED DURING COMPARATIVE PILOT PLANT SINTER TEST RUNS*

	Emissions Conventional Sintering Process lbs/hr	Emissions Improved Sintering Process lbs/hr	Percent of Conventional Sintering Process %
MATERIALS BALANCES Nos. 3 & 4			
Solid particulates - A	13.4	4.5	33.6
- B	21.5	4.7	21.8
Condensable particulates - A	4.1	0.6	15.8
- B	2.6	0.6	25.0
MATERIALS BALANCES Nos. 5 & 6			
Solid particulates - A	27.2	11.1	40.8
- B	23.7	11.8	49.8
Condensable particulates - A	2.6	1.1	44.3
- B	3.4	1.0	33.2

* Results from comparable continuous pilot plant runs at charge rates of 7,000 to 8,000 lbs/hr using raw materials comprised of iron ore, blast furnace flue dust, blast furnace sludge, BOF fume, mill scale, and limestone.

LIST OF CAPTIONS

Figure 1 - Isometric View of Sinter Bed Illustrating Zones of Reaction.

Figure 2 - Periodic Sinter Bed Temperature Gradients.

Figure 3 - Perspective View of Iron Ore Sinter Plant.

Figure 4 - Improved Sintering Process Draft Flow Arrangement.

Figure 5 - Materials Balance Diagrams Comparing Conventional and Improved Sintering Process.

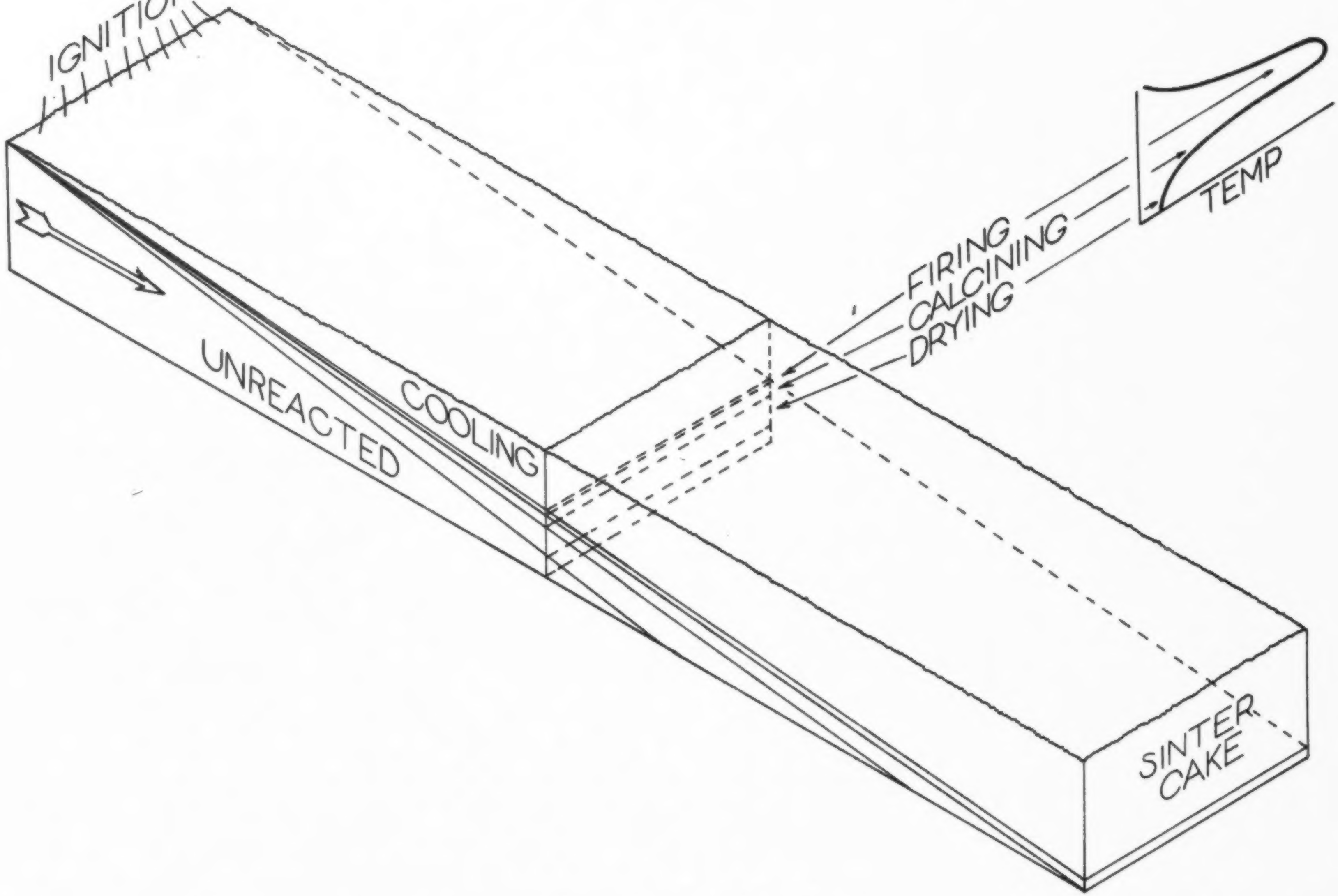

IGNITION
FIRING
CALCINING
DRYING
TEMP
COOLING
UNREACTED
SINTER CAKE

Figure 1 - Isometric View of Sinter Bed Illustrating Zones of Reaction.

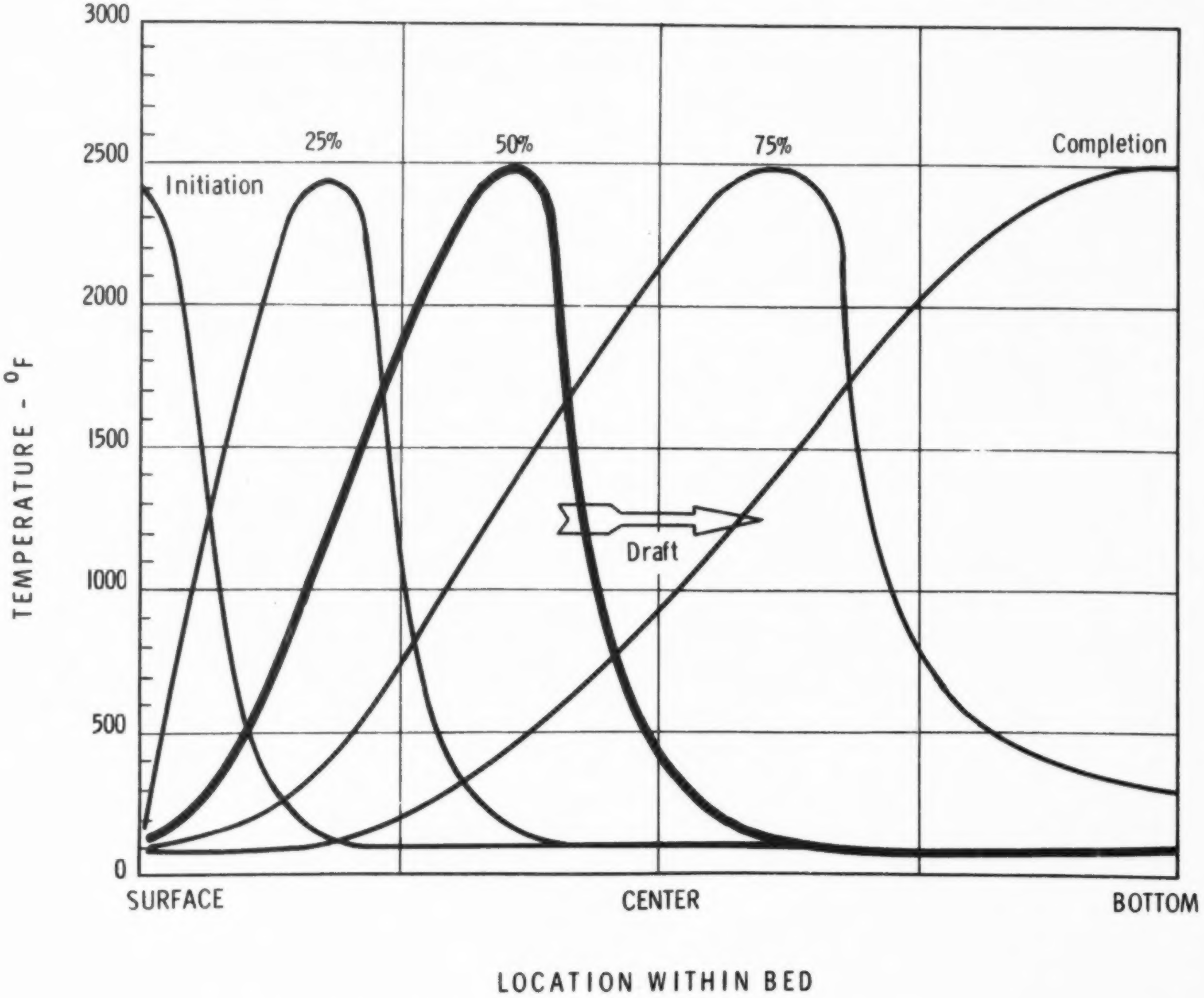
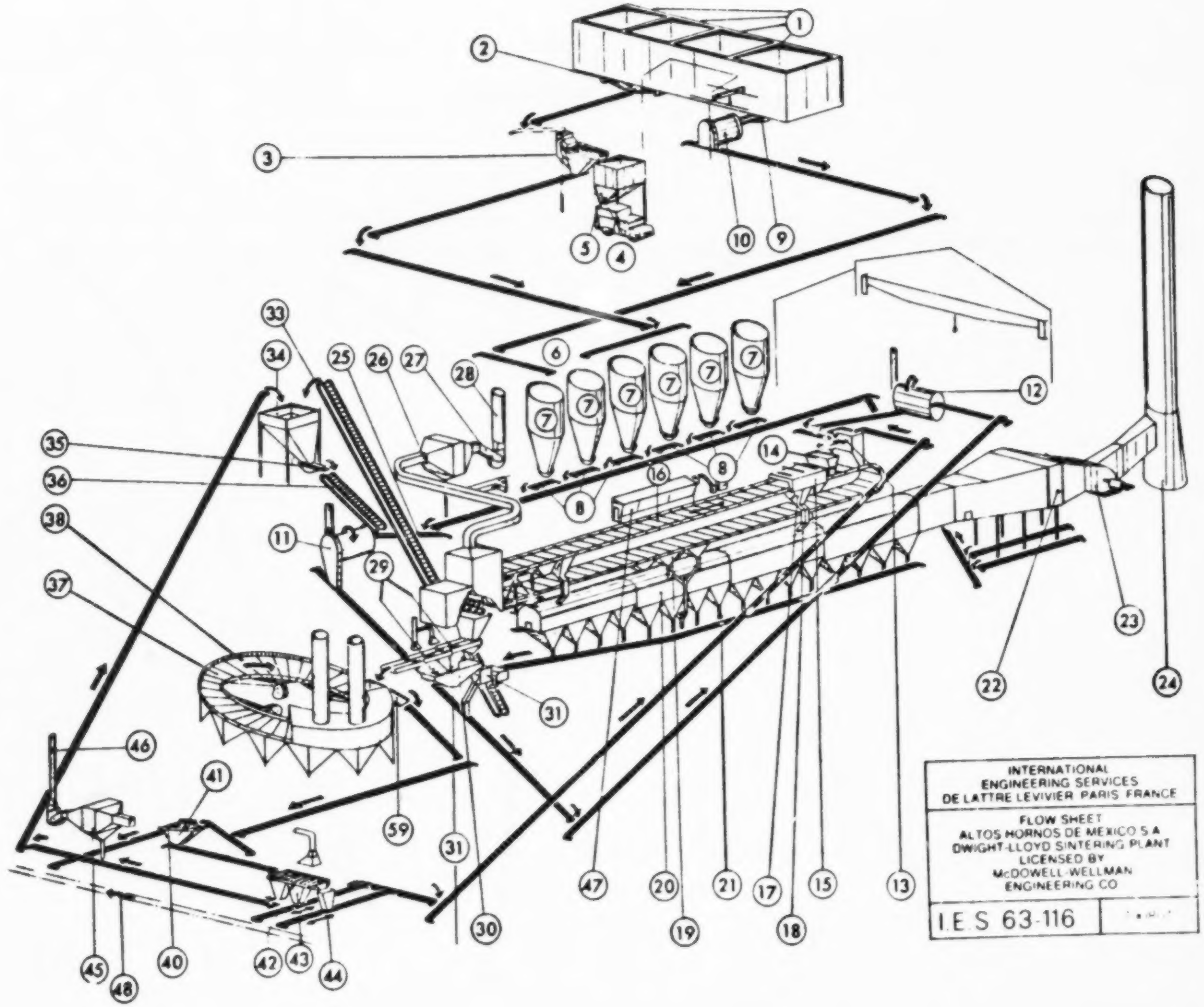


Figure 2 - Periodic Sinter Bed Temperature Gradients.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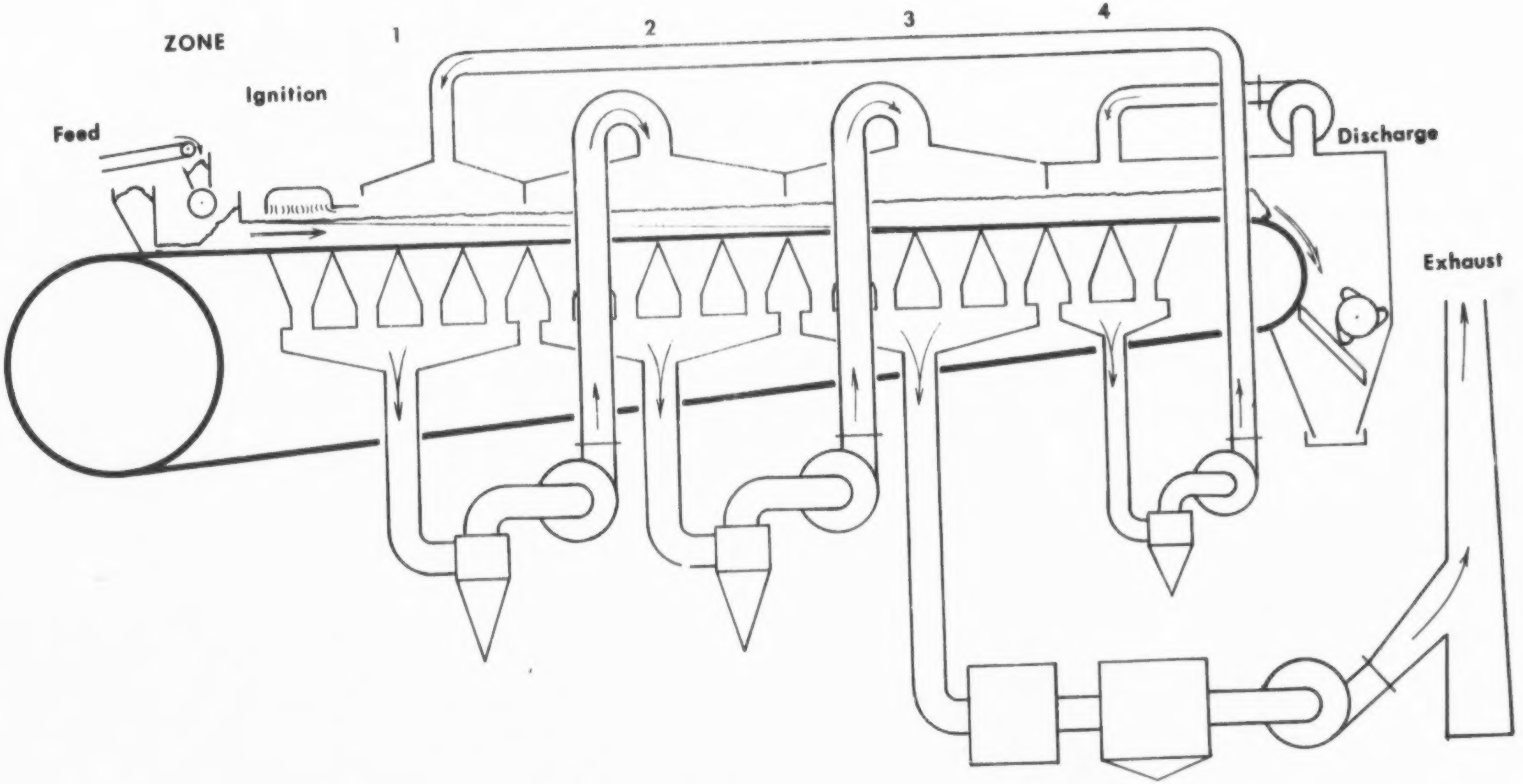
INTERNATIONAL ENGINEERING SERVICES
DE LATTRE LEVIVIER PARIS FRANCE
FLOW SHEET
ALTOS HORNOS DE MEXICO S A
DWIGHT-LLOYD SINTERING PLANT
LICENSED BY
McDOWELL-WELLMAN ENGINEERING CO
I.E.S 63-116

Figure 3 - Perspective View of Iron Ore Sinter Plant.


ZONE
Feed
Ignition
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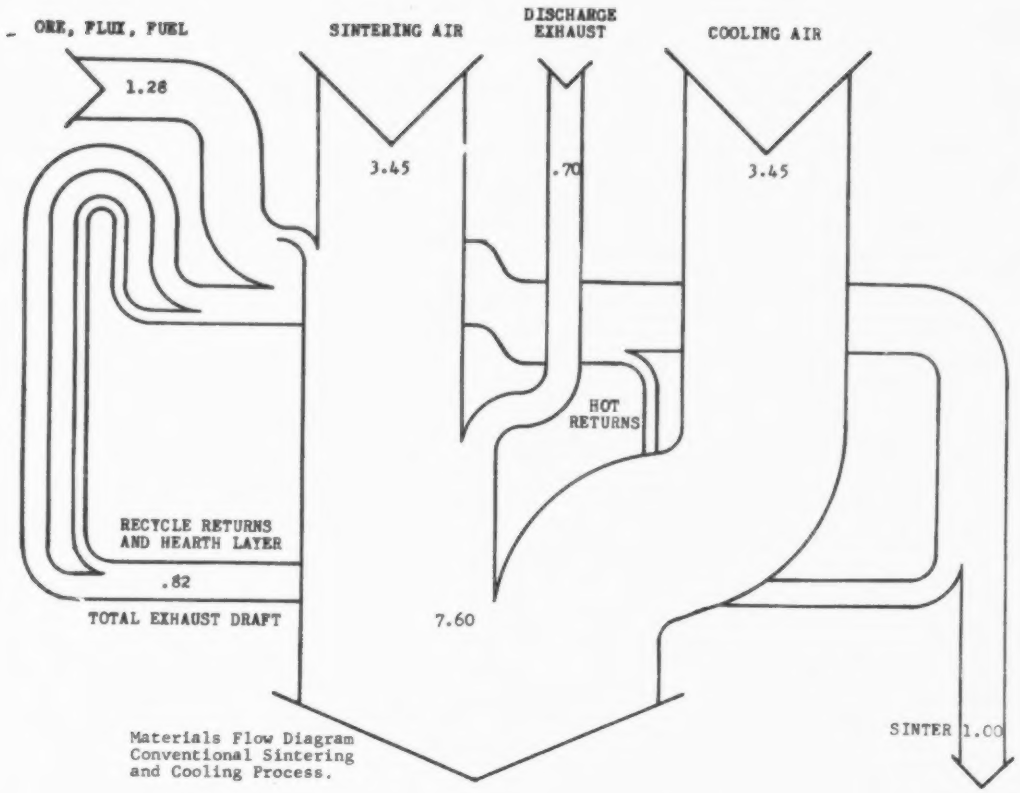
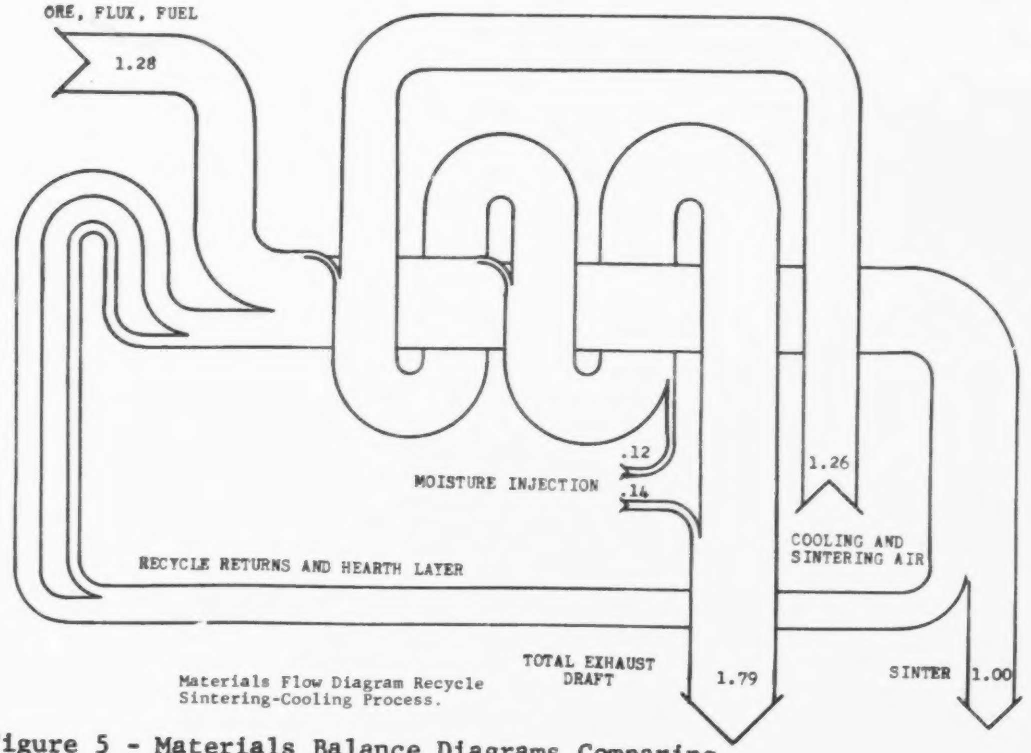
3
4
Discharge
Exhaust

Figure 4 - Improved Sintering Process Draft Flow Arrangement.


ORE, FLUX, FUEL
1.28
SINTERING AIR
3.45
DISCHARGE EXHAUST
.70
COOLING AIR
3.45
HOT RETURNS
RECYCLE RETURNS AND HEARTH LAYER
.82
TOTAL EXHAUST DRAFT
7.60
SINTER 1.00

Materials Flow Diagram
Conventional Sintering
and Cooling Process.


ORE, FLUX, FUEL
1.28
.12
MOISTURE INJECTION
.14
1.26
COOLING AND SINTERING AIR
RECYCLE RETURNS AND HEARTH LAYER
TOTAL EXHAUST DRAFT
1.79
SINTER 1.00

Materials Flow Diagram Recycle
Sintering-Cooling Process.

Figure 5 - Materials Balance Diagrams Comparing Conventional and Improved Sintering Process.

RTI/1736/03-01S September 1979

ENVIRONMENTAL ASSESSMENT OF COKE BY-PRODUCT RECOVERY PLANTS

by

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This paper identifies potential air pollution sources of environmental concern in coke by-product recovery plants. Data concerning the design and operation of existing plants and processes were collected. Since many process variations exist, a survey of the industry was carried out to determine the most common processes. Following this, the processes at a representative plant were sampled, using EPA's Industrial Environmental Research Laboratory RTP Level 1 protocol. Air pollutants of concern included benzene, cyanide, and polynuclear aromatic hydrocarbons. The air was sampled at suspected pollution sources, primarily storage tanks. The largest emission source was the final cooler tower where concentrations of aromatics at >50 g/Mg coke and cyanide at 278 g/Mg coke were found.

ENVIRONMENTAL ASSESSMENT OF COKE BY-PRODUCT RECOVERY PLANTS

This report discusses the findings of a screening study of the multimedia environmental effects of U.S. coke by-product recovery plants and their related pollution control technologies. The purpose of the study was to analyze relevant background data, to acquire new data by sampling and testing, and to draw conclusions concerning the environmental acceptability of the process.[1]

There are 60 coke by-product plants in the country; these processed gases from an estimated 44 million tonnes of coal in 1978. There are many potential air pollution sources for the by-product recovery plant. These are related to seven major operations: (1) tar processing, (2) ammonia processing, (3) final cooling-naphthalene handling, (4) light oil recovery, (5) desulfurization, (6) cyanide handling, and (7) water handling. For each operation there are alternative technologies, and existing plants employ only a few of the thousands of combinations of operations available.

Except for still vents and forced drafts (e.g., final cooler cooling tower), emissions to air are fugitives--tank breathing and working losses, open decanters, and basins. Fugitives are also due to faulty equipment, such as pump seal leaks and flange leaks. Light aromatics and polynuclear aromatics were positively identified as air pollutants, and polynuclear aromatics were indicated for other media.

One pollutant species of particular interest is benzene. Benzene has been listed as a hazardous air pollutant under Section 112 of the Clean Air Act (National Emission Standards for Hazardous Air Pollutants). To protect the public health from unreasonable risks associated with exposure to airborne benzene and polycyclic organic materials, a standard is being developed to decrease benzene emissions from the by-product plants. Emissions of carcinogenic air pollutants such as benzene are of particular concern since no safe level of exposure has been identified. Although the generation of benzene is an unavoidable consequence of coke production, most of the benzene which is produced in coke ovens is recovered, leaving typically only a small percentage that is emitted into the air. Potentially significant amounts of pollutants are emitted, however, due to the volume of plant throughput. The emissions of hazardous air pollutants are highly dependent on the type of processes used in the by-product plant.

PROCESS OVERVIEW

Although there are many possible process combinations, there are generally only two or three ways widely used in U.S. coke by-product recovery operations.

The gases leaving a coke oven are generally at around 700°C and of course contain all of the material to be processed in the by-product plant. Coke ovens are maintained at a slight positive pressure (1 mm water) to prevent air infiltration. As the gas leaves the oven, it is immediately subjected to spray cooling, both to cool the gas and to introduce a collecting medium for the tar as it condenses. After a short duct run the gas passes through a valve and enters a suction main, remaining below atmospheric pressure. At this point, the gas which has generally been cooled to the 100°C range condenses much of the water, tar, ammonia, and other low boiling point compounds.

Further removal by condensation is accomplished in the primary cooler. The tar and the water soluble compounds are separated by decantation. The tar is generally further dewatered before sale. If phenol is recovered from the ammonia liquor, it is often absorbed in an organic solvent before the ammonia recovery step. The ammonia liquor is traditionally steam-stripped to put the ammonia back into the gas stream. The waste ammonia liquor requires addition of a base to release some chemically bound ammonia.

Looking again at the gas stream, the exhauster is the fan which provides motive power for the gas. Both scrubbers and electrostatic precipitators are used in the industry for nearly complete recovery of the remaining tar in the gas. After the ammonia stripped from the waste ammonia liquor rejoins the gas stream, the ammonia can be scrubbed from the gas with a dilute sulfuric acid solution. Ammonium sulfate crystals form and are separated from the saturated liquor. The final cooler is a pretreatment step for light oil (benzene) recovery. In the process which generally uses contact cooling with water, naphthalene is condensed from the gas. The naphthalene may be removed from the water by absorption in organics or by flotation. Light oil is usually recovered by absorption in a petroleum fraction (wash oil). The light oil is steam stripped from the wash oil and recovered, and the wash oil recirculated. Desulfurization, if practiced, is intended to make coke oven gas a more acceptable fuel. Only a few large plants practice desulfurization. No process is in widespread use today.

At least three powerful influences militate against any single process description being widely applicable: (1) today's by-product plants have often evolved over 20-50 years of maintenance, design, and operational changes; (2) the technology is mature, and there are many proven alternate ways to recover chemicals; and (3) the market for coal chemicals is uncertain, and economic pressure has led to changes in operating philosophy.

EXPERIMENTAL

Based upon a review of the more common process combinations currently in use for by-product recovery, a representative plant was selected for Level 1 environmental assessment. The purpose of a Level 1 environmental assessment is to provide a screening or survey look at emissions from an industry, highlighting potential areas of environmental concern. The test work was done at the Fairfield Works of U.S. Steel Corporation near Birmingham, Alabama.

The Level 1 assessment protocol recommends that all identified emissions to all media be sampled and analyzed, as well as the feeds to and products from the process. All of the samples are grab samples, and the intended accuracy is to be within a factor of 2 or 3 of the actual emissions. Examination of the process flow of a by-product plant showed that most air emissions were fugitive and primarily composed of organic compounds. The potential for these fugitive emissions to contain significant amounts of aromatics and high molecular weight polynuclear aromatics (PNA's) was apparent. Hydrogen cyanide was also identified as a potentially significant component.

The sampling program developed for this study was centered on organic vapor emissions from tank vents and a cooling tower. Three types of sampling were used for the organic vapors: (1) glass bulb grab samples, (2) evacuated canister grab samples, and (3) 1 to 4 hour samples drawing the gas through an adsorbent resin, XAD-2. The glass bulbs were analyzed for light (C_1-C_7) hydrocarbons and volatile sulfur species using an on-site gas chromatograph (GC). Benzene and toluene were also quantitated with this GC. The evacuated canister samples were returned to the laboratory for analysis to identify and quantitate benzene, toluene, the xylenes, and ethylbenzene. The adsorbent resin was intended to adsorb hydrocarbons with carbon numbers greater than 7, or boiling points above about 100°C. The resin was extracted with a solvent and the extract analyzed in three ways:

(1) Total Chromatographable Organics (TCO), which is nominally the mass of organic compounds with boiling points between 200°C and 300°C.

(2) Gravimetric Analysis (GRAV), which is nominally the mass of organics with boiling points above 300°C; and

(3) Liquid Chromatography, LC, which is used to divide an extract into seven fractions (or cuts) which are graded by their polarity.

The analysis generally proceeds with a TCO and GRAV analysis of the original sample extract (preliminary), a concentration step to achieve a specified organic concentration (GRAV and TCO are also run on this concentrate), and then the LC work, with a GRAV and TCO determination on each LC cut.

The data for the plant site tested were developed utilizing methodologies based on the Environmental Protection Agency's Level 1 protocols,[2] with limited gas chromatograph-mass spectrometer identification of specific pollutants. The PNA's shown are the quantities of residual organics obtained upon evaporation of the solvent used for extraction, which are nominally those organics with boiling points above 300°C. The PNA's emission factors are subject to the additional uncertainty inherent in this method of estimation. Specific PNA's were not identified except for three sources considered most likely to involve them: the tar decanter, the dewatering and storage tanks, and final cooler cooling tower. Sulfur compounds are reported as hydrogen sulfide; cyanides, as hydrogen cyanide.

In addition to the Level 1 sampling and analysis, samples for hydrogen cyanide were taken at the final cooler cooling tower and 24-hour integrated samples were collected at three points around the plant boundary. The gas was bubbled through a sodium hydroxide solution for cyanide absorption and analyzed by wet chemistry.

To assist in the determination of the potential environmental significance of the various pollutant concentrations, comparison was made to values derived from the MEG's charts.[3] The most toxic compound in each of the 17 compound classes was identified, and its minimum acute toxic effluent (MATE) concentration was used for comparison. It must be kept in mind that the resulting ratio is biased. If it is well below unity, there would appear to be no concern for compounds in this class; if, however, the ratio is above unity, it is merely a signal for potential environmental concern.

TAR PROCESS EMISSIONS

The major potential emission sources for benzene and polycyclic organic materials are the tar decanting, dewatering, and storage operations.

The flushing liquor from the collecting mains is separated from the collected tar in a decanter. Tar decanters are often elongated, multi-compartment, rectangular tanks, the tar collecting on the bottom of the tank and flushing liquor being removed at the top. If covered, the tanks have hatches to allow access to the inside of the decanter. The temperature of the flushing liquor in the decanters is around 80°C. Another 20 percent of the tar is removed in the primary cooler which may be either a direct (spray type) or an indirect (shell and tube) facility. Both systems require cooling towers to cool the flushing liquor (direct) or cooling water (indirect).

In the tar decanting process vapor emissions occur because the flushing liquor is highly contaminated with organics, ammonia, hydrogen sulfide and other volatile compounds, the liquor is hot, and the decanters are vented. The available data indicate an emission rate of about 2.2 scm/metric ton coke produced, the vapor containing significant amounts of benzene and sulfur compounds. The rate of benzene emission from the tar decanter was 15.6 g/Mg coke production.

Flushing liquor holding tanks and primary cooler condensate tanks are similar in function. Both are potential fugitive vapor emission sources. The available data for the source indicates a total organic vapor emission rate of 1.7 scm/metric ton coke for all the tanks in this secondary decanting service. The rate of benzene emissions from these tanks was estimated as 9 g/Mg coke production. The emission rate is probably more dependent on the number of vents and tanks than on the volume of coke produced.

Tar dewatering is the process of reducing the water content of the tar below that which can be achieved in the decanters. Two types of dewatering equipment could be used: (1) mechanical, such as centrifuges, or (2) heating to elevated temperatures to drive off the water. The use of dewatering equipment depends on the requirements of the tar end-use.

In many existing plants, the coal tar is not refined on site but is sold to tar refiners. It is a common specification that this tar sold should contain no more than 2 percent water, but the tar underflow from the tar decanter generally contains much more than this. Accordingly, the crude coal tar is dewatered, ordinarily by heating it to reduce its viscosity and providing residence time for water droplets to coalesce and rise to the surface of the denser tar. If, as is commonly the case, the temperature is maintained above 90°C, then the combined vapor pressures of hydrocarbons over the tar phase and water over the aqueous phase can exceed one atmosphere. The result is a plume of steam and hydrocarbons issuing from the vent. There are no data available for dewatering by heating the tar. If the tanks are vented to the atmosphere, however, the emission would be significant due to the elevated temperatures and the presence of some relatively light organic materials, such as benzene in the tar.

Tar is commonly stored in heated tanks in order to facilitate handling. General industry practice has not been determined, but the available data indicate a storage temperature of about 80°C. In cases where tar storage is used to dewater the tar, an aqueous liquor will be present on top of the tar. The emission rate would be at least 0.14 scm/metric ton of coke based on working losses from the tanks.

Tar refining as a whole has not been tested as an emission source. Data are available on one potential emission source, tar distillation product storage, in particular "chemical oil" storage. Chemical oil is the light ends of the tar recovered after single stage flash distillation to separate the pitch. The organic vapor emission was fugitive from a tank vent, and was estimated at 0.024 scm/metric ton coke, again based only on working losses, with no data available on total emissions. For the remainder of the tar refining operation, most emissions could be expected to be fugitive vapors from tank vents, with potential emissions from vacuum distillation if the vacuum is drawn with steam jets.

The emissions from tar processing are essentially all fugitive vapor emissions from vented tanks. The primary sources are tar decanters, flushing liquor holding tanks, indirect primary cooler condensate holding tanks, tar dewatering, tar storage, tar refining, and tar distillation products storage.

FINAL COOLER

The emission sources identified for the contact, recirculating water type final cooler are those associated with the naphthalene separation from the water and emissions from the cooling tower. Naphthalene handling by melting/drying in vented tanks was another significant emission source.

After separation of the naphthalene, the water is commonly cooled in an atmospheric cooling tower and then recirculated to the final cooler. The basic function of the final cooler is to cool the coke oven gas from around 60°C to about 25°C in order to improve light oil absorption in the light oil scrubber.

Three forms of final cooler and naphthalene recovery technology are in use:

1. Cooling with water and naphthalene recovery by physical separation; or
2. Cooling with water and naphthalene recovery into tar in a tar bottom final cooler; or
3. Cooling with a wash oil which also absorbs napthalene.

About 25 percent of the plants utilize direct water cooling and physical naphthalene recovery, 60 percent utilize tar bottom final coolers, a couple of plants utilize wash oil cooling, and technology at the other plants is not known.

The choice of final cooler type will have a significant impact on the distribution of some pollutants in a by-product plant, cyanide being a good example. If the cyanide is not removed in the final cooler water, it remains in the gas and causes problems downstream. If it is not stripped out of recirculating cooling water, the blowdown will be high in cyanide and the wastewater plant will be more heavily loaded.

Naphthalene condenses in the final cooler water and is collected as a dirty brown slurry. Naphthalene will separate by gravity in a sump, or the separation may be enhanced with a froth flotation separator or similar equipment. The naphthalene may then be skimmed from the surface of the water.

The naphthalene crystals are wet with a film of mixed hydrocarbons, often of a brownish color, suggesting that some tar fog bleeds through the electrostatic precipitation and the ammonia saturator. This liquid hydrocarbon medium, of unpredictable amount, is a solvent for benzene. At these conditions (say 45°C, 5 psig) a liquid hydrocarbon would contain about three moles of benzene per 100 moles of liquid, perhaps 6 percent by weight, much of which would be evaporated during naphthalene handling and processing. (The naphthalene is, for example, conveyed some distance in open troughs, heated and "melted"--more precisely, dissolved in the accompanying hydrocarbon--to disengage water, then stored hot for convenience in handling.)

Since crude naphthalene has little market value, it is small wonder that more than half of all plants obviate the nuisance by some variant of the tar-bottom cooler. About one-fourth of the plants, however, handle naphthalene in some manner. Since there is more naphthalene in the tar than is recovered at the final cooler, and some of this naphthalene can be recovered in the course of tar refining, the tar-bottom final cooler does not rule out the production and sale of naphthalene.

The plant sampled began the separation with a froth flotation operation. No vent stream was at a rate sufficient to be measured, although there were visible wisps of vapor. The vapor directly above this liquid surface was sampled. The aromatic hydrocarbons are again of potential environmental concern. The naphthalene slurry which floated to the top of the water was skimmed and collected in open sumps, and the water was passed through a series of small basins to allow additional naphthalene separation.

Naphthalene collected as described above is impure and in roughly a 60 percent water slurry. Ths naphthalene slurry was pumped into a horizontal cylindrical tank. Once the tank was full, the water was decanted. Steam coils within the vessel were then utilized to dry and melt the naphthalene. This operation continued for one to two days. The vent rate was estimated to be 2.9 scm vapor/Mg coke by measuring the rate of air entering the vessel due to the chimney effect. The temperature in the tank was 101°C. Naphthalene was sampled at a concentration of 533 g/scm, which amounts to 1.56 kg naphthalene per Mg coke.

The final cooler unit, regardless if the tower is a direct-water once through or recycle, direct water-tar bottom, or wash oil operation, should not generate air emissions because it is designed as a closed system. Air emissions may be emitted, however, from the induced-draft cooling tower used in conjunction with the direct water and tar bottom final coolers.

The final cooler cooling tower has for some time been recognized as a potential source of cyanide emissions, and was sampled both for cyanide and organics. The level of cyanide in the water depends on the degree of cyanide stripping which is accomplished in the ammonia stills, along with final cooler operations and coal composition. At the site sampled, hydrogen cyanide was present in the gas leaving the cooling tower at an average concentration of 76.5 ppm, which corresponds to a mass emission of 0.28 kg/Mg coke (0.56 lb/ton).

This source accounts for more than half of the cyanide generated. The gas flow rate was estimated by assuming that the gas mass flow was equal to the known liquid circulation rate. The benzene emissions from the cooling tower were estimated as 51.6 g/Mg coke production from the estimated gas flow rate and the measured benzene concentration. The extent to which these components are dissolved in the water and then stripped into the air is dependent on the operation of the final cooler and cooling tower.

The second common way of handling the final cooler water is to pass the water through tar in the bottom of the final cooler and allow the naphthalene to dissolve in the tar. The naphthalene is then included with the tar in any additional refining operations. The efficiency with which naphthalene is removed by the tar was not available in the literature although it is apparently fairly high. The final cooler water is cooled in a cooling tower and recirculated to the top of the tower. Again, air stripping of light components in the water occurs to some extent in the cooling tower.

LIGHT OIL RECOVERY

Light oil is a clear yellow-brown oil, with a specific gravity of about 0.86. It is the coke oven gas fraction in which the more than 100 constituents with boiling points between 0°C and 200°C or so reside. Benzene is generally 60 to 85 percent of light oil, with toluene (6 to 17 percent), xylene (1 to 7 percent), and solvent naphtha (0.5 to 3 percent) being the more important of the lesser constituents. With few exceptions, light oil is recovered from coke oven gas by wash oil absorption in the United States. Light oil refining capability is present at about 35 percent of the plants. The products of the refining operations are mostly benzene, toluene, xylene, and solvent naphtha.

The emissions identified with light oil recovery include several decanted water streams, fugitive tank emissons, and a vent from the light oil condenser.

Several wastewater streams are decanted in the light oil plant. The primary source of the water is the live steam used to strip light oil from wash oil, and water must be separated from all the hydrocarbon liquids condensed from the still vapor as well as from wash oil. The waste could be avoided by using reboilers for non-contact heating with steam. They are commonly collected in the "intercepting sump" and treated in the combined wastewater treatment plant. The rate has been estimated at between 100 and 500 l/Mg coke depending on the ability of the operator to tightly recycle the water.

Fugitive emissions occur from wash oil storage, wash oil decanters, and light oil storage. Only the light oil storage tank was sampled, as it was amenable to data reduction by the tank working loss equation. The rate of benzene emissions was estimated as 3 g/Mg coke production. No emissions with measurable rates were present.

The noncondensibles vent off the light oil condenser was not accessible under Level 1 constraints and was not sampled. No data are available in the literature. This stream probably consists of the fraction of the coke oven gas which dissolved in the wash oil, as well as light oil vapor. This stream is thought to be quite small, appropriate for the 2-inch pipe used to vent the condenser.

MISCELLANEOUS EMISSION SOURCES

Leaking pumps, valves, and flanges are sources of benzene emissions in a by-product recovery plant when they are handling benzene containing materials. Some of the benzene containing liquids that are pumped include tar, naphthalene, crude light oil, and refined benzene. No data is available that specifically quantifies benzene emissions from the pumps, valves, and flanges of a by-product recovery plant. However, data is available on vapor emission factors from refinery processes that can be used for comparing the sources.[4]

Leaking pumps are the most significant sources, and the emissions from flanges are several orders of magnitude lower than from pumps. Emissions from valves handling light liquids are one order of magnitude lower than leaking pumps on a per source basis.

Wastewater handling and treatment is a necessary part of the coking operations, as raw coke oven gas contains water vapor driven from the coal in the coke oven. This water vapor is due to both surface moisture on the coal and bound water. Depending on coal type and coking practice, the flow of wastewater originating in the coke is around 100 to 200 l/Mg coke.

Wastewaters from other sources within the by-product plant are often combined with the waste ammonia liquor for treatment. Some of them are unavoidable; others can be either greatly reduced or eliminated by proper choice of process technique. The major secondary sources of wastewater are:

1. Barometric condenser water from steam jets used to draw vacuum on the ammonia crystallizer;
2. Steam stripping waste from wash oil and light oil decanters;
3. Blowdown from the final cooler.

Wastewaters are often carried in open sewers and may be held in open holding tanks, aeration basins, and biological treatment plants. Various organics that are partially dissolved or floating on the water may evaporate before the final effluent treatment. The wastewater may contain phenol, ammonia, cyanide, sulfur compounds, and hydrocarbons that can be emitted as fugitive air pollutants. No data are available on these emissions.

The transfer of crude light oil or refined benzene is a fugitive source of benzene emissions. These emissions are due to the displacement of air containing benzene by the liquid as the tank is filled. The problem of hydrocarbon vapor loss has been dealt with extensively by the petroleum refinery industry.

Filter cakes, tar and oil sludges, and slurries result from water treatment, sedimentation in tanks, and cleaning of pipelines and process vessels. These wastes are a potential source of fugitive emissions due to the evaporative loss of volatile organics they may contain. Handling procedures for these wastes include transport in open containers and trucks with subsequent disposal in pits or landfills.

MULTIMEDIA EFFLUENTS

In addition to air emissions, water and solid waste emissions also occur in by-product plants. Estimated emission factors for these pollutants, derived from sample data from one plant, are given in Table 1. Nine sources were investigated, seven by sampling. For the sources investigated, the daily total emissions were estimated from processing 1.8 million cubic meters per day of coke oven gas. The uncertainty in these values is anticipated to be a factor of 2-3.

TABLE 1. MULTIMEDIA ENVIRONMENTAL EMISSIONS

Light aromatics (mostly benzene),	372 kg/day
Polynuclear and high boiling aromatics (PNA)	57.6 kg/day
Sulfur compounds	108 kg/day
Cyanides	1,162 kg/day
Ammonia	334 kg/day
Phenols	5.6 kg/day
Light oils	40.1 kg/day

Light aromatics, the predominant emissions, were found in the highest concentration in emissions from the tar decanter, the primary cooler condensate tank, the naphthalene separator, the light oil storage tanks, and the distillation product storage tanks. PNA's (as total non-evaporables) concentrations were highest at the following sources: wastewater treatment sludge tar decanter, tar dewatering and storage, tar distillation products, naphthalene separator, final cooler cooling tower, and water from the biological treatment plant. Cyanide concentrations were highest at the final cooler cooling tower and in the aqueous effluent from the biological treatment plant. Sulfur compound concentrations were highest at the tar decanter, the primary cooler condensate tank, the naphthalene separator, the light oil storage tanks, and in the plant wastewater effluent.

The data suggest that the PNA's accumulate as a concentrate in the liquid streams (tars, flushing liquor, tar products, wash and wastewaters). PNA's accumulated in the water from the final cooler reentered the air as recycled water passed through the open cooling tower.

Ambient air samples, taken upwind and downwind of the by-product plant, showed increases in both benzene and cyanide concentrations. The following results were obtained:

TABLE 2. AMBIENT AIR CONCENTRATIONS AT A BY-PRODUCT PLANT

	Hydrogen Cyanide (volume ppm)	Benzene (volume ppm)
Downwind	0.062	0.8
Upwind	0.006	0.6
Gain	0.056	0.2
Toxic units/scm	toxic unit/scm	toxic units/scm
Downwind	0.0062	0.9
Upwind	0.0006	0.7

These results indicate that cyanide concentrations downwind of the by-product plant were well below levels for environmental concern. Cyanides of this plant were more a problem in wastewaters than in the air. Downwind benzene concentrations, on the other hand, were of potential environmental concern.

Some of the remaining unstudied sources include the wash oil storage, decanters, and condenser vents of the light oil recovery operations, the decanted water from the naphthalene dryer, the wastewaters from dephenolization, the tar-topping barometric condenser, and the cyanide handling processes, some of which are an inherent part of desulfurization operations. The wastewater streams involved in these operations were sent to a combined wastewater treatment plant at the study site.

The relative overall environmental impact of some of the pollutant sources within the by-product coke plant is addressed in Table 3. The biological treatment plant effluent is the most significant of the by-product plant sources. This was due to a combination of a large effluent rate and the sensitivity of the impact measurement to organic pollutant concentrations. The other major sources are the cooling tower for the contact final cooler and the biological treatment plant sludge.

TABLE 3. RELATIVE HAZARD OF BY-PRODUCT COKE PLANT POLLUTANT SOURCES

Normalized Relative Hazard	
Tar Decanter Vapor	0.036
Tar Dewatering/Storage Vapor	0
Primary Cooler Condensate Tank Vapor	0.017
Distillation Product Storage	0.001
Cooling Tower for Contact Final Cooler	0.349
Light Oil Storage Vapor	0.028
Biotreatment Plant Effluent	0.434
Biotreatment Plant Sludge	0.135

The procedure used to arrive at Table 3 uses a weighting process which considers pollutant concentration, hazard in the proper media, and emission rate. The ratios of the amount of pollutant emitted to the MATE values for each category were summed. The normalized relative hazard is the ratio of the summation for a source to the total for all of the sources. The MATE weighting factors were obtained from the Multimedia Environmental Goals.[3] For the by-product plant, the weighting factors reflecting the great hazard of certain PNA's essentially controlled the results. Weighting factors were obtained from the Multimedia Environmental Goals.[3]

This study is a limited-scope first look at the by-product plant from the environmental point of view. As such, it points to a need for control of light aromatics and PNA's. Control may be most likely achieved through techniques that essentially eliminate the sources: venting tanks back to the gas mains; blanketing with coke oven gas.

EMISSIONS CONTROL TECHNIQUES

A large proportion of the emissions from a by-product plant originate in the various vents in the plant. Recovery of vapor from these sources will generally be complicated by the presence of naphthalene. Wilputte Corporation[5] has installed water sprays on some tar decanters, and the techniques might be extended to other vents. Vapor recovery from these sources to the suction side of the exhausters, probably ahead of the primary coolers, might be possible. Venting to the gas main upstream of the askania valve is another alternative. The blanketing of holding tanks with coke oven gas which was originally used in the light oil recovery process to exclude air and prevent the buildup of sludges, eliminates the tank vents as an emission source. The blanketing gas is vented back into the main gas stream. This technique could perhaps be applied to many sources, even to refined benzene tanks, if the gases were first desulfurized to prevent deteriorization of the product. Problems to be addressed in considering the broader use of blanketing include making provision to admit the flammable gas into the various operating areas, and to prevent the condensation of naphthalene. Naphthalene condensation would require that the vents be heated, and the corrosive nature of the vapor (perhaps including chlorides) would cause materials problems. The system might be designed to float on coke oven gas at slightly above atmospheric pressure. This system when compared to internal floating covers offers an attractive alternative for small volume tanks, less than half a million gallons, and plants with multiple storage tanks which may be yoked together in a system.

The method for controlling emissions from the tar decanter consists of providing a water seal and a vent to the gas main at low pressure. The water seal is a heavy plate structure which is suspended from the roof of the tar decanter near the sludge discharge end. The major portion of the liquid surface is vented to the gas main near the coke oven battery. The tar decanter can be vented to the coke oven gas main to operate at a pressure of approximately 4 to 6 mm of water. The installation of the water-seal plate will be a comparatively difficult job. For retrofit conditions it will be necessary to take the tar decanter out of service, clean it thoroughly, and then make the installation after inspecting and repairing any hole that would allow the infiltration of air.

Naphthalene collection in open vessels inherently causes naphthalene emissions. Avoidance of exposed naphthalene by the use of a tar bottom final cooler and keeping the naphthalene in the tar are proven and should be preferable. A wash oil final cooler also collects naphthalene, but the naphthalene must eventually be removed from the wash oil. The final cooler cooling tower with a tar bottom final cooler would still have about the same level of cyanide emissions, although hydrocarbons emissions might be down. A wash oil final cooler should avoid the cyanide emissions, although the cyanide must go somewhere.

Some of the emission control systems for sources such as light oil storage are relatively inexpensive since the credits from the recovered benzene could pay for the system in a relatively short time. Other process modifications such as conversion to a wash oil final cooler would be more expensive, but could substantially reduce the overall by-product plant emissions.

REFERENCES

1. VanOsdell, D. W., et al. "Environmental Assessment of Coke By-Product Recovery Plants." EPA-600/2-79-016, January 1979.

2. Hamersma, J. W., et al. IERL-RTP Procedures Manual: Level I Environmental Assessment. EPA-600/2-76-160a, NTIS PB 257 850.

3. Cleland, J. G., and G. L. Kingsbury. Multimedia Environmental Goals for Environmental Assessment. EPA-600/7-77-136a and EPA-600/7-77-136b, November 1977.

4. Wetherold, R. and L. Provost. Emission Factors and Frequency of Leak Occurrence for Fittings in Refinery Process Units. EPA-600/2-79-044, February 1979.

5. Private communication with John Crosby, Wilputte Corporation.

COKE-OVEN DOOR SEAL DEMONSTRATION

by

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Coke making is a batch process for producing blast furnace and cupola coke through the procedure of carbonizing coals in narrow, vertical ovens. Each oven has a full-height door on either end. These doors are removed (for product discharging) and replaced each coking cycle (14 to 30 hours). There are about 25,000 coke-oven doors in operation in North America, ranging in height from 10 feet to over 20 feet. With an assumed average coking cycle of 20 hours, about 1,250 doors are handled each hour of the year.

Figure 1 is a photograph of one side of a coke battery showing: a) the narrow, vertical doors between the vertical supports of a battery, and b) the emissions that leak past the existing seals on these doors. The control of emissions leaking past door seals represents a difficult problem to many different groups, including the operators of coke batteries.

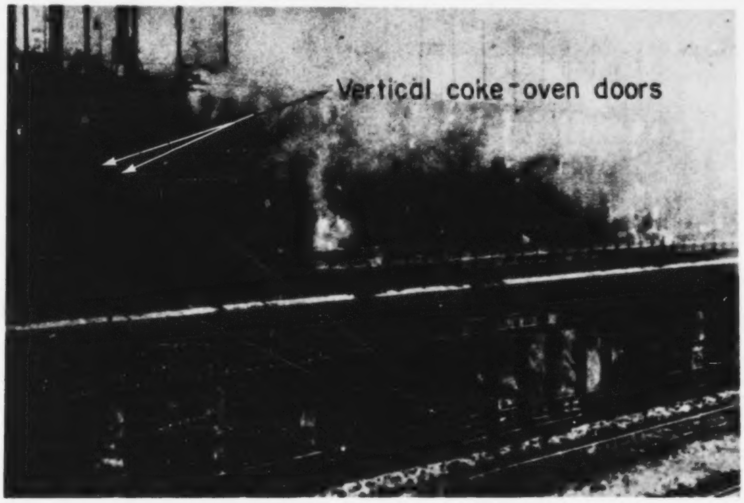


FIGURE 1. PHOTOGRAPH OF ONE SIDE OF A COKE BATTERY

The goal of this paper is to present the important elements of a research/development/demonstration funded by the EPA and the American Iron and Steel Institute (AISI), aimed at developing an improved and retrofittable system for sealing coke-oven doors. The Battelle-Columbus Laboratories were awarded the initial research contract in competitive response to the original Request for Proposal by the EPA. The contract was followed by funding for a development and a demonstration project.

Overall Objective of the Coke-Oven Door Sealing Program

As stated by the Sponsors, "the specific objective will be to innovate and to develop at least one system that will be proven in the field to be retrofittable to existing coke ovens, mechanically and physically suitable for commercial use in steel plants, and highly effective in containing and controlling emissions from ends of ovens."

We were given to understand that the Sponsors wanted an analytical, technical approach working within a developed set of criteria, leading to firm recommendations. There was to be no empirical testing of new seal ideas at coke batteries prior to making our recommendation.

Project Organization Within the Program

The overall program consists of three projects:

1. Study of Concepts for Minimizing Coke-Oven Door Emissions(1)
2. Development of Concepts for Minimizing Coke-Oven Door Emissions(2)
3. Demonstration of the Recommended Retrofittable Coke-Oven Door Seal.

In the first project, 45 different concepts for new coke-oven door seals were evaluated. These concepts were obtained from every possible source, including surveys of sealing methods used in industries other than the steel industry. The major conclusion of this project was that upgraded metal seals have the best potential for being developed into more effective seals. It was recommended that these upgraded seals should have increased flexibility and improved resistance to heat distortion.

The development project has been completed and has resulted in a recommendation of seal design and material. Details of the development project have been described in reports and a paper(3) and will not be covered here. Rather, a discussion of the recommended seal design and material, and the first results of the demonstration project will be presented.

Definition of Terms

Retrofit is usually defined as furnishing new parts or equipment not available at the time of manufacture. This definition fits the program but was expanded to include the criterion that the retrofit be accomplished with a minimum of equipment modification or replacement of parts. Effective refers to the elimination or virtual elimination of seal emissions. In addition, "effective" includes:

a) a long successful life and lowest possible "life cost",and

b) adaptability to all or almost all batteries, including those in which the doors and jambs have been warped in service.

Considered a bonus would be an effective operation in which the effectiveness depends more on the characteristics of the design rather than on the skill and conscientiousness of the workers in making seal adjustments.

Brief Background Description of Existing Seal Designs

Existing seal designs, in general, can be classified into two groups. They are either a spring design or of the stiff "fixed-edge" designs.

In the United States about 75 percent of the operating coke ovens that need retrofit door seals have the S-shaped spring design shown in a cross section view in Figure 2. This is a venerable design that we have seen operate completely emission-free when new and when given what appeared to be special adjustment attention. This design is about 30 years old.

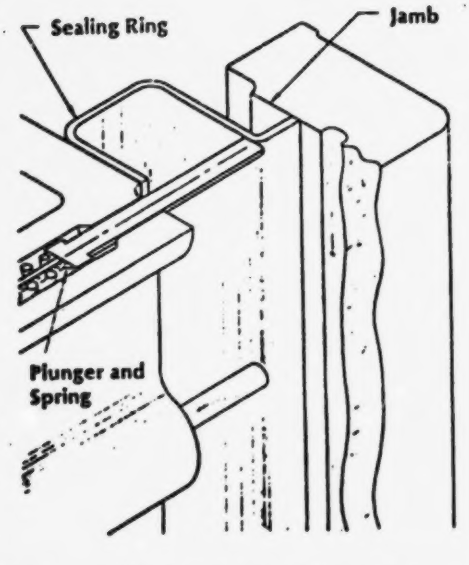


FIGURE 2. Side View of S-Shaped Seal System

The fixed-edge designs are used in about 25 percent of the operating batteries. Views of these designs are given in Figures 3 and 4. Such designs are inordinately stiff in the vertical direction and we have never seen emission-free performance from seals with these designs, regardless of the attention given to adjustments of the bolts. It is a fact that a knowledgeable worker can minimize leaks with this design if given enough time between movements of machinery; but people willing to develop and exercise such skills are now becoming an endangered species.

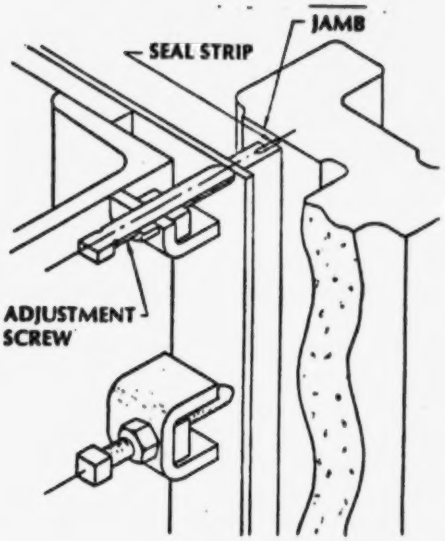


FIGURE 3. Side-View of Adjustment Equipment on Fixed-Edge Seals

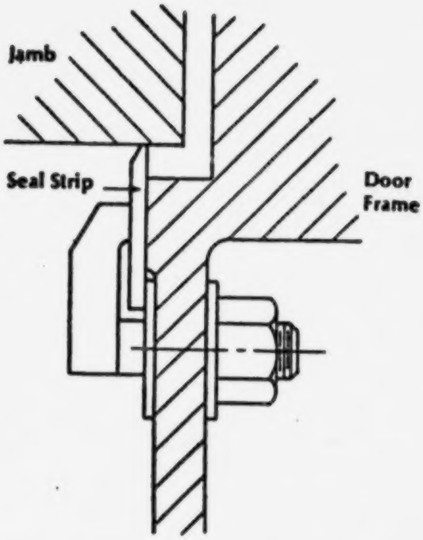


FIGURE 4. Cross-Section of a Typical "Knock-Type" Seal

It is worthy to note that all existing designs produced by engineering companies and others require periodic adjustments along the edge of the seal. A coke-oven door has one shape or profile when it is cold. However, on being heated to operating temperature there is a slight but significant change in profile. In fact, there is a change in the profile of the door and the attached seal with every change in the temperature differential across the door, e.g., during a rain storm. In this respect, a spring seal provides a resilient element that can better accommodate itself to temperature-induced changes in the distance between the jamb and the doorback. In our development work we concentrated on developing a spring seal with increased flexibility and decreased susceptibility to heat distortion.

The concept of having a multitude of adjustment bolts and springs along the 100-plus miles of coke-oven seal-edge length in day-to-day operation has advantages and disadvantages. Some of these will be discussed in the presentation of the recommended seal. There is, however, an apparent and an accepted logistics problem in finding the time between machinery moves to make these adjustments. In many plants it is not a question of having available seal-adjustment labor or skills, or possessing appropriate portable elevator equipment to move men into location; rather, it is a question of the limited amount of access time during daylight hours. Based on our observations, one of the criterion of the development project was to incorporate automatic gap-closure capability in the design, i.e., to develop a method of eliminating or minimizing the need for manual adjustments to achieve sealing effectiveness.

Recommended, Retrofittable Seal

Within the design requirements (and restraints), the seal design that evolved in the development project is shown in Figure 5. A list of descriptive elements and expected advantages is given as follows:

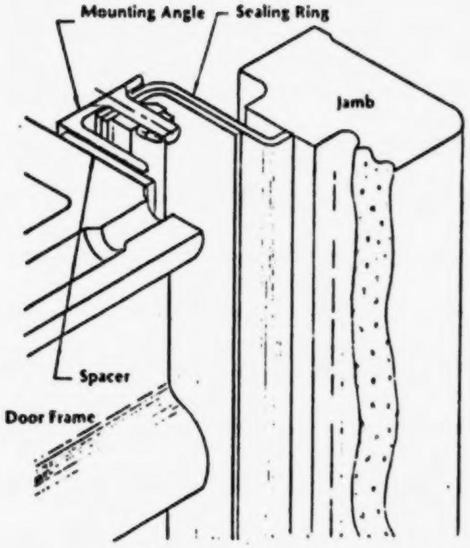


FIGURE 5. Side View of Recommended EPA/AISI Retrofittable Seal

1. The entire seal consists of the carbon-steel mounting angle and the simple, two-bend main seal with one back-up or reinforcing leaf. The back-up leaf can be used to absorb some of the high levels of latching force now being used in the coke industry. All seals are deflected outward when doors are latched in place with force levels of about 20 tons. There are indications in the demonstration project that, as expected, the back-up leaf may not be required.

2. The recommended alloys for the main seal are high-performance, high-temperature alloys known to have a long operating life in heated spring applications. Taking into consideration fabricability, thermal expansion coefficients, and other factors, our recommended first choice in the demonstration project was a nickel alloy (Inconel X-750). Subsequent evaluations should be completed using lower-cost alloys. Inconel X-750 can be heat-treated at 1400 F to give yield strengths of up to 8 times higher than those for alloys presently used in seal fabrication. This increased yield strength and the alloy's high resistance to creep at 800 F and lower make it possible to safely increase the seal deflection about three-fold over that of existing spring seals without distortion.
3. The height of the seal lip that contacts the jamb has been lowered to 3/8-inch. This increases the seal flexibility along the height of the jamb by a factor of 10 over the flexibility of existing seals. As proven in laboratory testing, the combination of increased seal deflection during door latching. along with increased seal flexibility along the length of the jamb will result in automatic closing of minor gaps caused by "unevenness" in the jamb contour, and it will also "iron out" minor irregularities in the as-manufactured straightness of the seal edge. For various reasons some operators of coke batteries would like the seal lip to be wider than 3/8-inch. The performance of wider-lip widths is expected to be evaluated once the recommended seal design has become accepted.

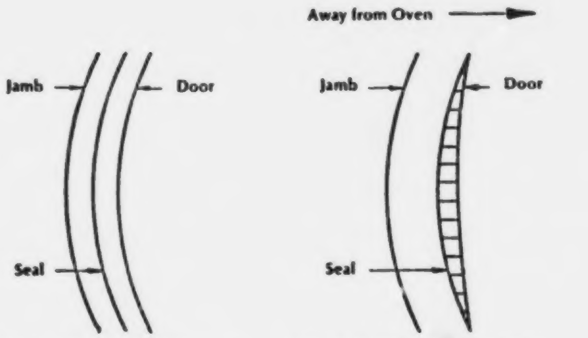
4. Part of the plan to use high-strength alloy material in this design was to eliminate the need for adjustment bolts and adjustable plunger-spring seal supports on the recommended design. The seal alone should conform to the requirements without any assistance or adjustments. This approach will also eliminate the distortions seen on standard spring seals caused by the point loading on the back of these seals.

The use of high-performance alloys will result in a more expensive seal because of the higher price per pound for alloy, plus the need for heat-treatment following fabrication. To counter this unfavorable situation, the seal weight was lowered and the design was adjusted for high-volume fabrication methods. A single-leaf seal for a 6-meter-tall oven weighs only 84 pounds but it is more resistant to physical damage than the existing spring seals. In high volume production of these seals, the forming can be done by low cost hydroforming of the corners and roll forming of the sides of the seals. With roll forming it is expected that all machining of the seal edges may be eliminated.

Retrofit Conditions and Procedures

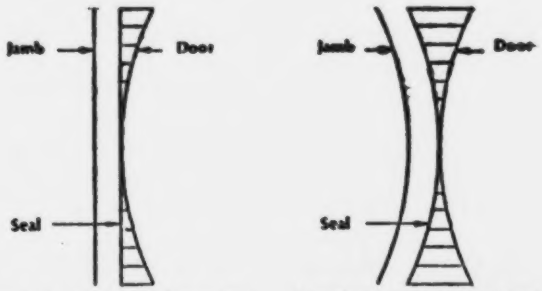
As previously stated, the recommended seal design is to be more flexible, it is not to have adjustment bolts or spring plungers on the end of the seals, and yet it is to be retrofittable to all end closures including those that exhibit extreme jamb and door warpage conditions. In many circumstances the recommended seal is expected to be bolted into place without any special considerations, and the inherent flexibility of the seal must accommodate any minor variations in the profile relationships between the jamb and door. This remains to be established. However, one interest in the EPA/AISI seal shown by the coke plant operators is its potential for effectiveness where the jamb and door profiles are very incongruent. If this potential can be realized, it would not be necessary to replace jambs. For incongruent profiles, a retrofit procedure had to be developed.

As background to this effort, it should be appreciated that all door frames or doorbacks have bowed profiles attributable to temperature differentials across the doors. All jamb and door profile combinations are incongruent to some degree; otherwise, there would be no need for adjustment bolts and springs in existing seals. Figure 6 presents an exaggerated example of variations that exist for relative contours of jambs and doors. This figure indicates the required buildup under the seal (shaded areas) to achieve congruency of seal edge with jamb. It is this buildup approach under the seal holder that became the recommended retrofit procedure.



Example A. Horizontal distances between jamb and door are all the same.

Example B. Door has less curvature than jamb. Jamb corners are closer to door than at the middle of jamb/door.



Example C. Door is curved inward and is facing either a straight jamb or distance between jamb and door is greater at the corners.

Example D. Jamb and door bow towards each other.

FIGURE 6. Exaggerated Examples of Variations That Exist in Terms Of The Relative Contours of Jambs and Door Frames

At the first demonstration site, a new type of incongruency was encountered in which the jamb and the door are bowed outward in the center, away from the coke oven. The measurement data that were obtained are plotted in Figure 7 by using different scales for the presentation of the horizontal and vertical measurements. In the retrofit procedure used for this incongruent situation, only the variation in the horizontal distance between the jamb and the inboard side of the doorback is of

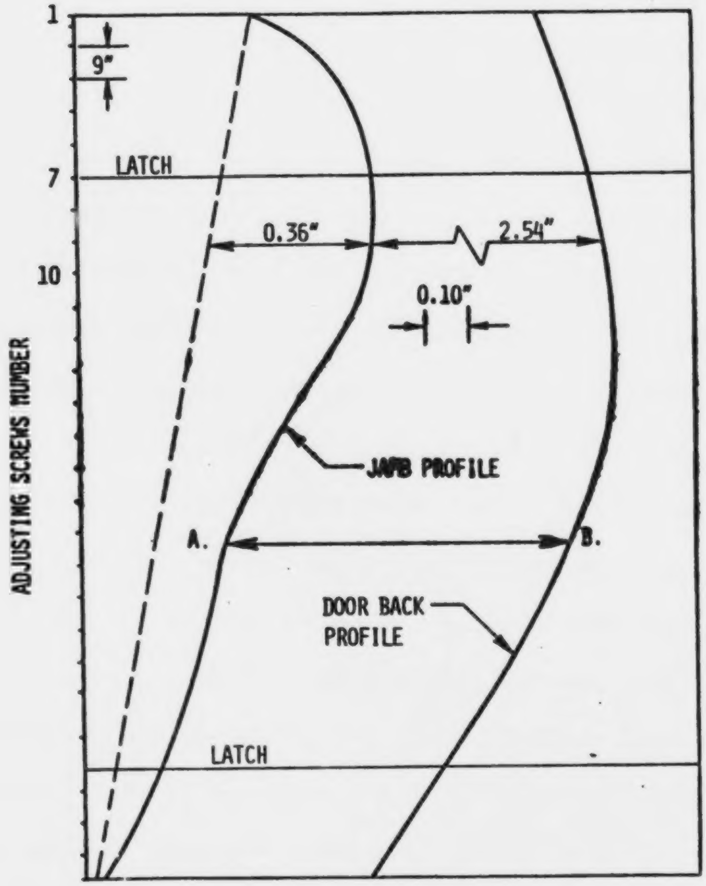

1
9"
LATCH
7
0.36"
2.54"
10
0.10"
ADJUSTING SCREWS NUMBER
JAMB PROFILE
A.
B.
DOOR BACK
PROFILE
LATCH

FIGURE 7. JAMB AND DOOR PROFILES.
OVEN 973, PUSHER SIDE

interest because this is the space that the seal must "fit" and be effective. These are the A to B distances along the length of the doors shown in Figure 7.

At first, considerable effort was expended in developing measuring methods to obtain the A to B measurements. However, in this instance these measurements were taken by merely (a) turning in the adjusting bolts to positively set the screws on the seal while the door was on an oven, (Figure 4), and (b) measuring the height of the adjusting screws above the doorback in the repair station. Any minor variations in measurement accuracy are countered by the high flexibility of the seal.

The recommended retrofit procedure to remedy the incongruent profile situation is to substitute a one-time measurement and seal-setting procedure for the periodic adjusting-bolt manipulation. As an example, for the jamb and door profiles shown in Figure 7, the height of the seal edge at the latch levels must be close to 2.3 inches in order to permit door mounting. From these reference points and the A to B measurements obtained, it is not difficult to determine the amount of seal-height adjustment along the height or length of the door to obtain seal edge-to-jamb congruency. These determinations for one case are plotted in Figure 8. Note that the range in height above the doorback is about 0.4 inch. This may be well within the flexibility range of the seal to maintain contact with the jamb without making any effort to set the seal height. However, for the early stages of the demonstration project we elected to set the seal height. The recommended method for setting seal height is to use metal spacers under the seal holder.

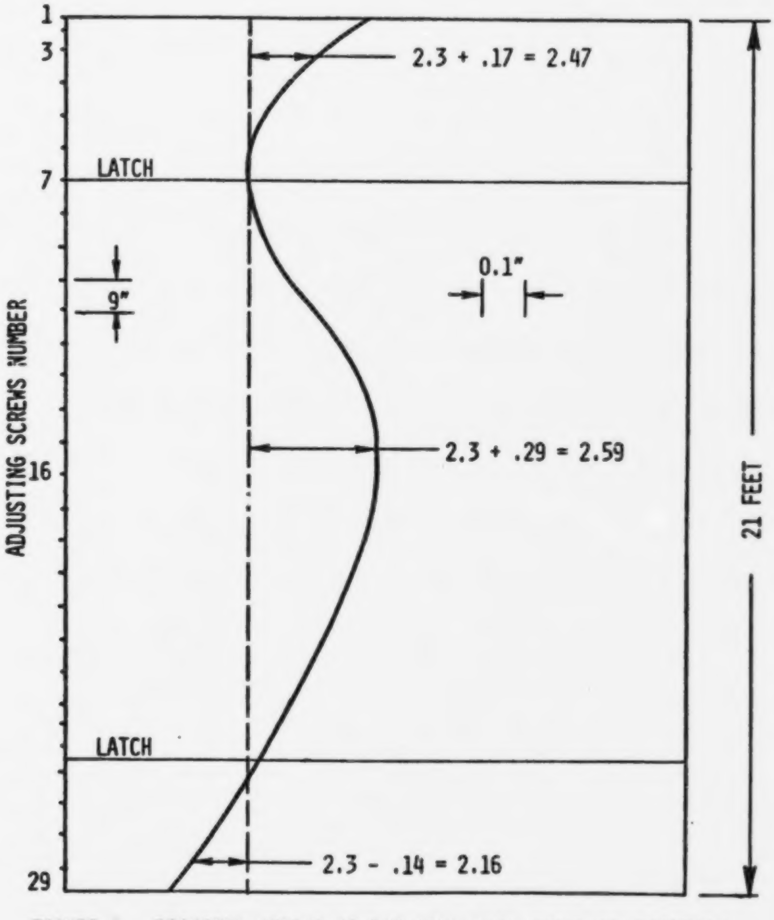

1
3
7
16
29
ADJUSTING SCREWS NUMBER
LATCH
LATCH
2.3 + .17 = 2.47
9"
0.1"
2.3 + .29 = 2.59
2.3 - .14 = 2.16
21 FEET

FIGURE 8. REQUIRED HEIGHT OF THE SEAL EDGE ABOVE THE DOORBACK TO GET THE SEAL CONGRUENT WITH THE JAMB WHEN AT OPERATING TEMPERATURES. OVEN 973

Taking measurements at operating doors and then setting a variable seal height to obtain near-perfect congruency is not desirable from the viewpoint of some coke plant operators. One expressed criticism is that this procedure will prevent the movement or shifting of doors between ovens inasmuch as the seal on one door is custom fitted to one jamb. However, the practice of keeping ovens and doors together is already in operation at several plants. In the future it is expected that there will be workable compromises. For example, it is anticipated that the majority of doors and jambs on a battery will have similar congruency patterns. It may, therefore, be possible to shift doors within this regime without problems. Also, any problem doors can be removed for straightening or even bending to shape. This approach is is much preferred to replacing jambs. There are other alternatives that can be considered depending on the overall operating results of the retrofit seals.

The Demonstration Project

The first problem that arose while planning and scheduling the demonstration project was that the established fabricators to the steel industry were overloaded with work, and for a long time (over 6 months) no fabricator showed any interest in producing prototype seals of an unfamiliar alloy. Also, fabricators having experience with high-strength alloys did not want the entire contract consisting of purchasing, tool-making, forming, and heat-treating. To encourage bidding and to convince the fabricators of the importance of this project, the AISI Project Officer obtained commitments from six steel companies to (a) purchase 32 seals for demonstration at 8 batteries, and (b) divide the cost of the fabrication tooling required. This approach, coupled with personal visits, did not result in any response. This log jamb was broken when Bethlehem Steel Corporation (a) ordered the sheet alloy, (b) requested Bethlehem Engineering to adapt the recommended seal to a fixed-edge battery, (c) ordered the fabrication tooling required, and (d) placed a priority order for the fabrication of four seals for the 6-meter battery (fixed-edge seals) in Lackawanna (Buffalo) New York. As per agreement with enforcement agencies, a schedule was set for engineering, fabrication , and demonstration.

The adaptation of the recommended seal to a battery having fixed-edge seals is a complex matter because these batteries exhibit a design distance of only 2.3 inches between the jambs and the doorbacks, as compared to a distance of 3.6 inches in the majority of designs having a spring seal. Bethlehem Engineering followed the conceptual design outlined in our reports and Figure 9 shows the resulting seal attachment method.

There were some potential problems in this compromise design. In adjusting the height of the seal it was necessary to release and move the seal only, rather than shift the seal and its holder as a unit. This design was accepted by Bethlehem/Battelle based on faith in the increased flexibility of the recommended seal.

Prototype testing is rather straightforward in description, i.e. put the prototype into its intended service and evaluate the results relevant to the expectations. After delays by the fabricator, the four 21-foot-long seals became available for mounting on doors. The first two seals were equipped with back-up leaves and the seal heights

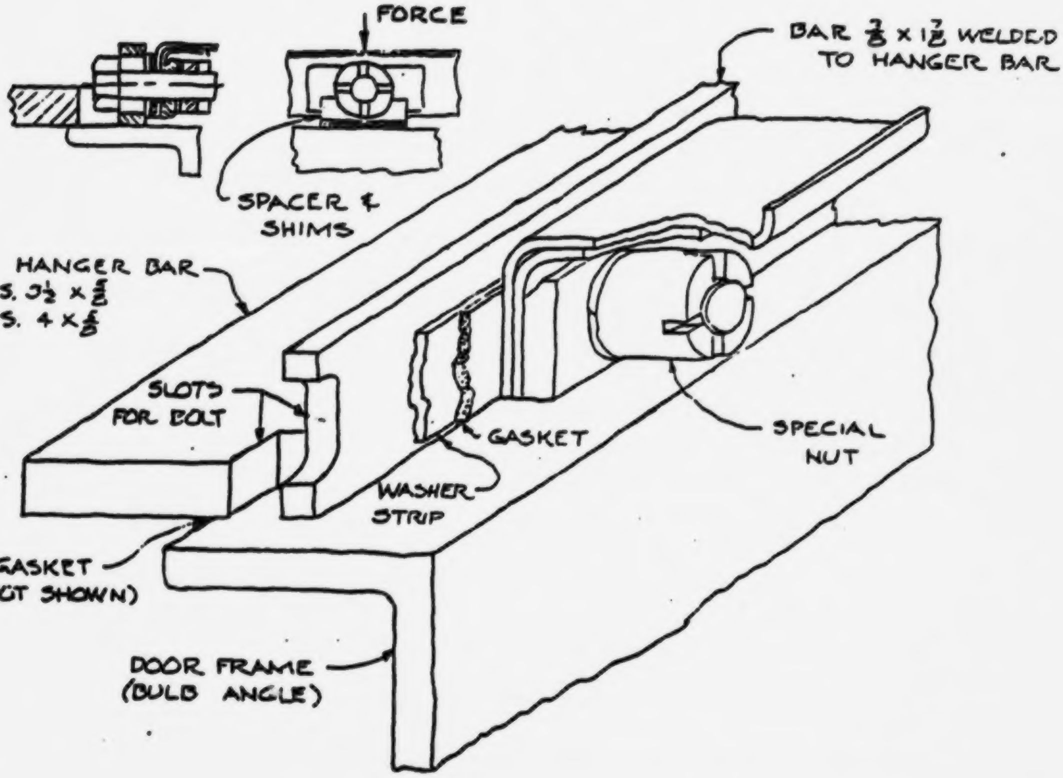

FORCE
BAR 7/8 x 1 7/8 WELDED TO HANGER BAR
SPACER & SHIMS
HANGER BAR
C.S. 5½ x 5/8
P.S. 4 x 5/8
SLOTS FOR BOLT
GASKET
SPECIAL NUT
WASHER STRIP
GASKET (NOT SHOWN)
DOOR FRAME (BULB ANGLE)

FIGURE 9. First Seal Attachment Method, (Lackawanna Ovens) a Fixed-Seal Type of Door.

were set on the doors using the method previously described. These demonstration seal doors were placed on the selected oven the next time this oven was discharged in daylight hours. In a few minutes we were aware that our joint efforts with Bethlehem Steel were being only partially rewarded. In both seals, the 84 total feet of vertical seals were emission-free, but the 8 feet of seal across the ends of the doors (top and bottom) released emissions. The conformity of the seal to the vertical portions of the warped jamb was as expected and this conformity was maintained as the door profile changed in response to heating. The emission control at the top and bottom ends of the seals was, however, ineffective.

Because of pressure to get the four demonstration seals into operation, a third seal was installed, but in this instance the back-up leaves were omitted to increase the flexibility of the seal ends. There was some measureable improvement in gap-closing ability on the seal ends but in general the emission pattern was the same, i.e., rated ineffective at top and bottom.

In the development effort, special technical attention was directed toward the design of the corners of the seal. The study of the problem centered on improving the geometry of the existing S-shaped seal corners. The development effort included measurement of the deflection and gap-closing capability of a full-scale stainless model of the recommended seal-end (two corners attached to a cross piece). These development efforts increased the measured deflection capability of the corners. For example, the corners were given an inside radius to minimize stress concentration in the corners, and welds were displaced from the corners as shown in Figure 10.

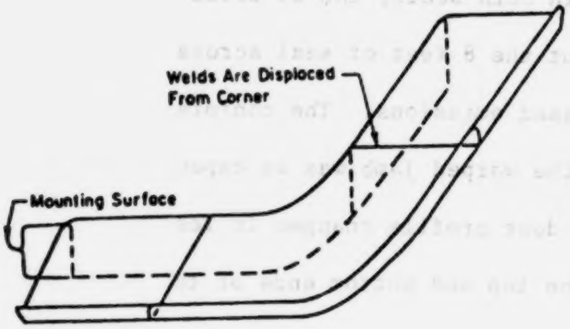


FIGURE 10. Completed Corner of AISI/EPA Seal

With the localized seal leakage problem that developed, an investigation was started working with tools built for measuring the unevenness of the seal edges on the ends. Also evaluated was the gap-closing capability of the demonstration seals. The results obtained are shown in Figure 11. When the seals were originally fabricated, the edges were machined flat while being clamped to the holder. The end profiles are shown in Figure 11a. When released from the bars some unevenness developed in the end edges, probably caused by the residual stresses introduced during the final machining operation. (Figure 11b). However, when the bar was bolted to the door and the seal was bolted to the bar, the unevenness of the seal in the critical end of the seal became pronounced (figure 11c). Pressing a plane surface against the end seal to deflect the seal 0.3 inch did not completely close the gaps (Figure 11d) and

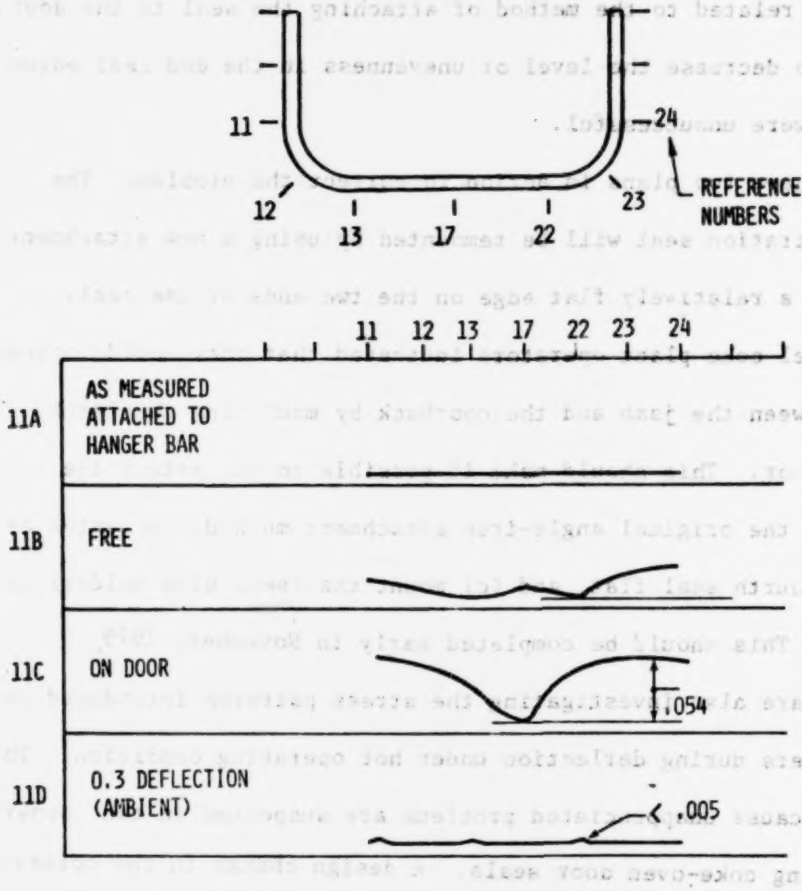


FIGURE 11. FIELD DATA SHOWING THE UNEVENNESS OF THE SEAL EDGE ON THE END OF THE DEMONSTRATION SEALS UNDER VARIOUS CONDITIONS. DISTANCES SHOWN ARE GAPS REMAINING BETWEEN THE SEAL EDGE AND A PLANE SURFACE

this seal leaked emissions while in operation. It is apparent that the unevenness of the seal edges as they now exist is beyond the gap-closure capability of the seal design, and it is inferred that the seal unevenness is related to the method of attaching the seal to the door. All efforts to decrease the level of unevenness in the end seal edges in the field were unsuccessful.

We have two plans in action to correct the problem. The fourth demonstration seal will be remounted by using a new attachment method to start with a relatively flat edge on the two ends of the seal. Bethlehem Steel coke plant operators indicated that they could increase the space between the jamb and the doorback by machining the latch bars on the door. This should make it possible to (a) attach the seal by using the original angle-iron attachment method, (b) grind or machine the fourth seal flat, and (c) mount the (seal plus holder) on the fourth door. This should be completed early in November, 1979.

We are also investigating the stress patterns introduced in the seal corners during deflection under hot operating condition. This is being done because unappreciated problems are suspected in the corners of all existing coke-oven door seals. A design change in the corners might increase the gap-closing capability of spring seals.

It is our judgment that the ends of the recommended seals can be made to perform in a manner as effective as the vertical portions of the demonstration seals. Unfortunately , this need for a problem-solving step in the demonstration project has made it impossible to conform to the schedule given to us.

References

(1) "Study of Concepts for Minimizing Emissions From Coke-Oven Door Seals". This report may be obtained from the National Technical Information Service as Report Number PB 245580.

(2) "Development and Demonstration of Concepts for Improving Coke-Oven Door Seals: Interim Report". This report may be obtained from the National Technical Information Service as Report Number PB 286628.

(3) Hoffman, A. O., Paul, Ralph L., "The Development, Description, and Status of the Retrofittable AISI/EPA Coke-Door Seal". Presented at the AIME Ironmaking Conference in March 1979 in Detroit.

ENVIRONMENTAL ASSESSMENT OF COKE QUENCH TOWERS

by

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SYMPOSIUM ON IRON AND STEEL POLLUTION TECHNOLOGY
PICK-CONGRESS HOTEL
CHICAGO, ILLINOIS

OCTOBER 30, 31 and NOVEMBER 1, 1979

ABSTRACT

The body of information presented in this paper is directed to those individuals concerned with quantifying gaseous and particulate emissions from the coke quenching process. Both dry and wet quench systems will be discussed.

Results of testing programs at the Lorain Plant of U.S. Steel, DOFASCO's No. 2 Coke Plant in Hamilton, Ontario, and an Eschweiler Bergwerks-Verein (EBV) plant in Erin, W. Germany, will be presented. Testing methodology will be reviewed and emission results compared.

SUMMARY

An environmental assessment of air emissions from various types of quench towers was made based upon data collected by York Research Corporation at

- U.S. Steel Corporation Lorain Works
- Dominion Foundries and Steel (DOFASCO) Hamilton, Ontario Works
- Eschweiler Bergwerks - Verein (EBV) Works, Erin, West Germany

Estimates of particulate emissions rates from the natural draft quench towers at Lorain and DOFASCO, and the pressure quench system at Erin are presented. Organic emission rates from the Lorain quench tower are reviewed and the environmental impact of dry quench towers also discussed.

The quench tower exhaust at Lorain contained 3.5 pounds of particulate per ton of coal when contaminated water was used for quenching. In addition, gaseous emissions such as sulfur dioxide, ammonia, phenol, and cyanide contributed 0.5, 0.3, 0.2, and 0.01 pounds per ton of coal respectively. When clean (river) water was used as makeup to the quench tower, particulate emissions were reduced by more than one-half and gaseous emissions were reduced by one order of magnitude.

Fifty three different organic compounds were found in the Lorain quench tower emissions; seven of these, including benzo(a)pyrene, were found in sufficient quantity to be considered a potential health hazard. The use of waste water from other coke plant sources for quenching greatly increases the organic load when compared to quenching with river water. Although the water itself is a principle source of organic emissions, the coke also appears to contribute to the emission of organic pollutants. Since the majority of organics detected are either gaseous or associated with small particles, they will contribute to ambient air contamination beyond plant boundaries.

Particulate emission tests conducted at DOFASCO's No. 2 Coke Plant Quench Tower using river water averaged 0.466 lb/ton of coal. Particle size data indicated that the majority of the particulate emissions were less than 10 microns in diameter. The DOFASCO particulate data could be deduced from the Lorain data when taking differences in quench water quality and baffle design into consideration. Particulate emission rates from the EBV pressure quench system cyclone averaged 0.612 lb/ton of coal using river water.

Dry quenching has the advantage of virtual elimination of air and water pollution problems associated with conventional wet quenching. Dry quenching is performed in a closed-cycle system using continuously recirculated inert gases to cool the hot coke.

INTRODUCTION

Coke Manufacturing

The majority of coke manufacturing in the United States is performed to supply the steel industry with blast furnace coke. There are two generally accepted methods for manufacturing coke; the beehive process (nonrecovery) and the by-product, or chemical recovery process. Today, the by-product process produces about ninety-nine (99) percent of all metallurgical coke.

In a by-product coke plant bituminous coal is heated, out of contact with air, to drive off the volatile components. The residue remaining in the ovens is coke; the volatile components are recovered and processed in the by-product plant to produce tar, light oils, and other materials of potential value, including coke oven gas. This process is accomplished in narrow, rectangular, silica brick ovens arranged side by side in groups called batteries.

Coal is charged through holes into the tops of the ovens from hopper bottom cars which run on tracks over the top of the battery. During the coking period, the gases and volatile materials distilled from the coal pass into the collection main(s) which run the length of the battery. At the end of the coking period, the doors are removed from each end of an oven and a long arm pushes the incandescent coke into the quench car. The car then moves to the quenching tower where the coke is cooled by water sprays. The cooled coke is delivered to handling equipment for subsequent use as a basic raw material for the blast furnaces.

Coke Quenching

The common practice in the U.S. steel industry for cooling incandescent coke is wet quenching, an operation which produces billowing clouds of steam, water droplets and air contaminants. The operation involves the direct application of water sprays in towers which are so constructed as to draft much of the resulting quench plume up from the immediate work area. The water used for quenching may be once-through river water, river water recycled from prior use in quenching, or contaminated waste ammonia liquor and other coke plant wastewaters.

Typically, 10 to 20 ton loads of hot (2000 + ^{o}F) coke are quenched by 6,000 to 12,000 gallons of water. Each quench takes about 2 to 3 minutes and produces huge billowing clouds of steam, water droplets, and air contaminants. In order to draft these emissions out of the work area, quenching takes place under towers which are open at the bottom to admit the coke car. Baffles are often fitted in the tower above the quench car to reduce the amount of large diameter particulates emitted and the amount of make-up water needed. Water not expelled from the tower is recycled back to the sump.

Due to the high visibility of the quench tower plume, the quenching operation has been a subject of intense interest to those who promulgate and enforce environmental regulations. Although the quench tower has been historically viewed primarily as a source of particulates, organic emissions have recently been of concern as evidenced by the fact that quenching is being considered by EPA as the subject of a National Emission Standard for Hazardous Air Pollutants.

Quench Tower Emissions

Due to the short, intermittent bursts of emissions, high moisture content, presence of droplets, flow variability, and other factors, an accurate assessment of the magnitude and nature of air pollution from quench towers has not been well established. Many pollution control engineers have theorized, however, that significant amounts of coke plant water contaminants (particularly dissolved solids) directed to quench tower sumps for disposal were transformed by the quenching process into air pollutants which escaped the baffles. Quench water contaminants could also leave the quench tower, however, by being deposited on the cooled coke or by being dredged after settling (or possibly precipitating) to the bottom of the sump.

PROCESS DESCRIPTIONS

Lorain Works of U.S. Steel Corporation

At Lorain, the coke ovens are about 30 feet long and average 18 inches wide, being wider at the car end than at the pusher end. The recovered coke gas is burned in flues located between the walls of adjacent ovens; typically, coke plants use about 40 percent of the gas to heat the ovens, with the remainder being used elsewhere in the steel mill. At this plant, there are 413 coke ovens in use in seven batteries, each battery consisting of 59 ovens. These ovens are normally operated three shifts per day, seven days per week, and the plant converts upwards of 7,000 tons of coal per day to coke. Normal coking time is 17 to 18 hours. However, this varies with the condition of the oven.

The quenching operation at Lorain utilizes approximately 9,000 gallons of water per quench and is described in Figure 1. Contaminated quench water is made up of process wastewater which includes tar still wastewater, waste ammonia liquor from the primary cooler, ammonia absorber and crystallizer blowdown, light oil (benzol) plant wastewater, and gas desulfurizer and cyanide stripper wastewater.

Quench Tower No. 1 at Lorain was equipped with a baffle arrangement as shown in Figures 2, 3, and 4. The 45° baffles were constructed in such a way as to allow a vertical area of one inch between the bottom of one baffle and the top of another. This vertical open area permitted a portion of the stack flow to pass straight through the baffles with little opportunity for impingement on the baffle surfaces. Furthermore, several baffles had been removed (or destroyed) and this provided additional open area.

DOFASCO, Hamilton, Ontario

DOFASCO's Hamilton, Ontario plant is a fully integrated basic steel producer. The specifications of the three coke plants which supply metallurgical coke to the four blast furnaces are given in Figure No. 5. The emission sampling program was conducted at DOFASCO's No. 2 Coke Plant Quench Tower. This plant consists of two batteries of 53 ovens each. Approximately 16 tons of coal is charged into each oven. After a coking time of 16-17 hours, the coke is transported to a wooden rectangular shaped quench tower. In the quench tower, approximately 5000 USG of water is sprayed directly on the 11 tons of coke, cooling it from approximately 2000°F to 180°F. This cooling water is supplied from a 10,000 gallon head tank through eight spray nozzles. The various phases of the quenching cycle are indicated in Figure 6. The water flows into a 60,000 USG sump located adjacent to the tower. It then flows into a clean well through a stainless steel screen. Bay water is added to the clean well by float control to make up evaporative losses.

The quench tower is constructed of treated wood, is 56.5 ft. high and has an exit area of 652.5 ft^2. Two rows of 1" x 4" wooden baffles are located 9' 9½" below the tower outlet. Each row is inclined 20° to the vertical with a 2" spacing between rows and 3-5/16" spacing between the baffles. Eighteen water sprays are located above the baffles. These are turned on once a shift in order to wash down any solids which have accumulated on the baffles.

Eschweiler Bergwerks - Verein, Erin, W. Germany

The EBV plant at Erin has five coke batteries approximately 20 years old. The ovens are 4.2 meters high, with a capacity of 15.6 metric tons of coal. Typical coking time was 16 hours and oven temperatures were approximately 1350°C.

The EBV Pressure Quencher consists of a special quench car with a coke container designed to receive the entire load of incandescent coke without moving. A narrow hood is attached to the guides and the quenching station. At the quench station a lid is clamped on the coke car and a measured amount of city water is sprayed on the coke through nozzles in the lid. The amount of quench water (city water) and the flow rates are controlled. During the YRC tests these were fixed at a predetermined optimum setting of 570 gallons/min for 3.5 minutes (or approximately 2,000 gallons per quench). When the water contacts the hot coke it cools the coke by evaporation. The steam is superheated by the hot coke and is vented into a large cyclone. A typical pressure quench cycle is tabulated below:

TYPICAL PRESSURE QUENCH CYCLE

	Cumulative time		Time Interval	
	min	sec	min	sec
Push starts	00	00	00	00
Push		35		35
Transfer quench car to quench station	2	05	1	30
Lower lid	2	45		40
Lock lid (scrubber water on)	3	15		30
Quench water-on (test period)	6	45	3	30
Unlock lid	7	00		15
Raise lid	7	30		30
Move car to wharf-dump and return next oven	9	30	2	00
Lower hood ready for next push	10	00		30

TEST METHODOLOGY

Previous test methodologies to determine the magnitude and nature of air pollutants from quench towers were often flawed by sampling difficulties such as the exclusion of certain size particles or limited in the measurement of necessary process parameters. Attempts by state and local agencies to measure particulate emissions utilizing standard EPA sampling equipment were also limited in their scope and encountered a number of sampling difficulties.(1,2) Major problems occurred because the short, violent, rush of steam did not allow accurate reading and adjustment of the sampling equipment to maintain isokinetic conditions (the EPA method contemplates measuring velocities and making adjustments every 3 to 5 minutes--more than the total time of the quench). Also, droplets in the exhaust stream plugged filters and made determinations of the molecular weight of the gases nearly impossible. In addition, the short duration of the quenches made capturing the prescribed volume of gases extremely difficult. The shape of most quench towers, and the use of internal partitions probably compounds these problems by causing uneven flows across the tower cross-section.

In order to minimize sampling error, a number of modifications were made to the standard EPA particulate sampling train. A high volume sampler was used to minimize the time required to collect sufficient gas volume and sample weights. A cyclone was fitted on the front of the probe to collect droplets and large diameter solids. This addition allowed more accurate determination of moisture in the stack gases, prevented filter plugging, and provided a means of particle and droplet sizing. Also, the use of a Hastings-Raydist velocity meter with continuous recording and continuous purge enabled more precise evaluation of isokinetic sampling rates. Details of YRC's sampling methodology have been discussed previously.(3-6)

RESULTS

Lorain

In order to quantify emissions from the quenching process and to determine the nature and source of these emissions, YRC was contracted by the EPA to evaluate the process. The site selected for the research program was U.S. Steel Corporation's Lorain Works. Two separate test programs were conducted on the No. 1 Quench Tower, the first in 1976 (for particulate and general gaseous emissions) and the second in 1977 (for specific organic emissions).

Particulate Emissions

The particulate emissions data obtained during the 1976 tests are summarized in Table 1.(5) The plume exiting the stack at Lorain contained an average of 3.5 pounds of particulate per ton of coal when contaminated water was used for quenching. This was considerably larger than the quench tower emission factor of 0.9 pounds of particulate per ton of coal. Particulate emissions were drastically reduced when clean water was used as make-up for the coke quench tower. Overall reduction was by more than one-half, to approximately 1.6 pounds of particulate per ton of coal.

Size distribution information for the particulate (and droplet) emissions was provided by the structural design of the sampling train. Particles (or droplets) within specific size ranges tend either to be collected by, or to settle out in, certain structural elements of the train. The cyclone collected particles and droplets predominantly $\geq$ 10 μm. Particles and droplets between 0.3 μm and 10 μm (averaging 3-4 μm) were deposited in the probe and the filter collected particles $\geq$ 0.3 μm. The impingers (back half) collected SO_x and particles <0.3 μm.

A substantial portion of the large size particulate (>10 μm) is believed to be due to thermal shattering of rapidly quenched coke and erosion by turbulent water sprays.

The quantity of large sized particles and droplets collected at Lorain is comparable to the findings of earlier researchers. However, the quantity per quench of smaller particles (<10 μm) collected at Lorain was an order of magnitude greater than the quantity of larger particles. The average particle size of the total particulate emission was found to be approximately 3-4 μm.

Particulate concentrations in quench water were also determined and are presented in Table 2.(5)

Figure 7 shows the total amount of particulate matter measured by the sampling train versus the total dissolved solids content of the quench water lost up the stack.(5) Each is expressed in pounds per ton of coal. This graph suggests a strong relationship between quench tower emissions and contamination in the quench water. However, it also shows that not all of the emissions were related to water contamination levels. For example, the graph indicates that even if water with no dissolved solids was used to quench, approximately 1.4 pounds of particulate per ton of coal would be emitted from the Lorain tower.

Gaseous Emissions

Table 3 presents the results of gaseous emission tests as average gaseous emission rates (lb/ton of coal) for four compounds using both clean and contaminated quench water.(5) It is evident that emission rates for these gases are strongly dependent on quench water quality.

The gaseous contaminants found in inlet quench water and subsequently in stack emissions, are evolved from several sources, including coke oven flushing liquors, and the incandescent coke itself. (See Table 4.)

Organic Emissions - Lorain (1976)

Three stack tests were conducted to quantify organic emissions. Table 5 presents the results of these tests.(5) The data are grouped into several categories of organic compounds. The aromatic heterocarbons are clearly predominant. Polynuclear Aromatic Hydrocarbons (PAH) were also investigated and these results appear in Table 6.(5) Some of the lower molecular weight PAH were present in equal or higher amounts in the stack emissions collected than in the quench water.

So few samples were analyzed that no accuracy could be assigned to these tests and the results were inconclusive. However, the data suggest several interesting characteristics of quench tower organic pollutants. A substantial quantity of organics, 1 to 8 lb/ton of coal, may be emitted. These emissions are bulk aromatic in nature and a small part of the total organics is represented by Polynuclear Aromatic Hydrocarbons.

Organic Emissions - Lorain (1977)

Fifty-three (53) different organic species were identified and quantified in these quench tower emission tests, many found in significant amounts. Many of these organics were part of the class of Polynuclear Aromatic Hydrocarbons and others were polar compounds (heterocyclic oxygen and nitrogen compounds).

The PAH test results for the three different test conditions (considering water quality and coke greenness) are shown in Table 7.(7) It is clear that the concentration of organics in the quench tower plume increases greatly when contaminated water is used and, to a lesser degree, when green coke is being quenched. This trend was also revealed by statistical analysis of the data.

Three sample trains representing the three test conditions were analyzed in detail by sampling train component to help determine the physical characteristics of the organic emissions from quench towers. These results indicate that most of the PAH found in each test was in the organic adsorber unit, which means this material is either gaseous or associated with particles smaller than 0.3 micron. These respirable particles can remain airborne over long distances and can penetrate deep into the lungs.

Samples of clean and contaminated quench water were taken and analyzed for PAH and polar compounds (Table 8). The contaminated water was the major source of organic emissions as evidenced by the high organic content of the water.(7)

Because of the interest in using benzo(a)pyrene (BaP) as a surrogate for PAH emissions, a separate analysis, highly specific for BaP, was conducted. Table 9 shows significant amounts to be present. BaP was not detected in every test; however, during those tests in which BaP was detected, its concentration exceeded the Minimum Acute Toxicity Effluent Value.(8,9) There appears to be no correlation between concentrations of BaP and other organics, hence, it does not seem to be a good indicator of the concentration of other organics in the quench tower emissions.(7)

A comparison of the organic emissions data with various rating systems showed that the following compounds considered to be toxic, hazardous, or carcinogenic (8,9,10,11) are present in the quench tower plume:

- Benzo(a) pyrene
- 3-Methyl cholanthrene
- 7,12-Dimethyl benz(a)anthracene
- Dibenz(a,h)anthracene
- Dibenzo(a,h) pyrene
- Dibenzo(a,i) pyrene
- Benz(a)anthracene(s)
- Pyridine
- Indeno(1,2,3-cd)pyrene
- Phenanthrene
- Phenol
- Cresol
- Quinoline

DOFASCO

Emission sampling was conducted by YRC at Dofasco's No. 2 Quench Tower between August 15 and September 1, 1977. Prior to the actual sampling, however, extensive reliminary testing was required. At a meeting held with the Ministry of Environment, it was determined that 12 points in a horizontal cross-section would be tested. Two levels were suggested, 4' 6" and 2' above the baffles. The 4' 6" level was ultimately selected since flow testing indicated a more uniform gas flow at this level (refer to Figure 8). Velocity profiles were performed at each of the 12 sampling points. A typical velocity profile is shown in Figure 9. Gas velocities and gas temperatures during the first water spray period were consistently higher than during the second water spray period. (Fig. 9 & 10). The average gas velocity and temperature range during emission sampling was 10.1 ft/second and 155-170°F, respectively. The overall average stack gas flow was 395, 400 ACFM. (12) Preliminary tests indicated that the moisture in the gas leaving the quench tower averaged 27% and peaked at 38% during the water spray periods of the quenching cycle.

In all, 18 separate particulate tests were performed. Each test consisted of three individual quenches at two sample points for a total of six quenches per test. A total of 108 quenches were tested over the sampling program.

Wind speed much greater than 10 mph would cause significant shearing of the quench plume. Tests were conducted, therefore, only during periods of low wind velocity. Wind conditions were found to be most suitable in the early evening. The average wind speed during testing was 5 mph.

Total particulate emissions (front plus back half) for all tests averaged 0.466 lb/ton of coal. Three modes of quenching operation were tested during the sampling program. Nine particulate tests conducted under normal operating practice using recycled quench water averaged 0.464 lb/ton of coal. In an attempt to achieve better particulate removal, the baffle sprays were turned on and recycled water was used during two tests. The particulate emissions for these tests averaged 0.368 lb/ton of coal. Six tests carried out using once-through Bay water for quenching averaged 0.573 lb/ton of coal. Composite samples were collected of water entering the quencher sprays. A typical analysis of recycled quench water and Bay water is shown in Figure 11. Test results indicate that particulate emissions do not vary significantly for the three modes of operation tested.

Various process parameters, including coking time, coking temperature, and emissions during pushing (amount of green coke) were monitored during the emission testing in order to determine their effect on particulate emissions. The pushing emissions were ranked by visual observation, prior to quenching, on a scale of one to five. A ranking of one denoted very little particulate emission. The rankings ranged from one to four with an average of 2.6. Coking times averaged 14.8 hours ranging from 14.2 - 15.5 hours. Oven temperatures (average of coke side and pusher side) averaged 2340°F, ranging from 2280 - 2410°F. Correlations of particulate emissions with greenness, coking time, coking temperature and sample point location could not be found.

Six particulate samples were saved from the cyclone catch for particle size analysis, microscopic analysis and Coulter Counter analysis. The particulate caught in the 10 micron cut size cyclone accounted for 9.4% of the front half particulate catch. Microscopic analysis indicated an average particle size of 63.1 microns and a range of 4.86 - 294 microns. The Coulter Counter analysis indicated a median particle diameter of 64.5 microns. The particulate caught in the probe accounted for 75.9 wt % of the particulate catch. The remainder, 14.7 wt %, was found on the filter paper. Since more than 90% of the particulate passed through the 10 micron cut size knockout cyclone, it may be concluded that the majority of the particulate was less than 10 microns in size.

ERIN

The pressure quencher at the Erin Plant of EBV was tested by YRC in October, 1978.(13) The objective of the program was to obtain preliminary particulate emission data on the quencher cyclone exhaust and a pilot 2500 ACFM venturi scrubber. The venturi scrubber operated at approximately 17-18 in. W.C. with a liquid-to-gas ratio of 10-11 gallons per 1000 ACFM. Quencher water and scrubber inlet water was relatively clean, containing 253 mg/l of dissolved solids and 3 mg/l of suspended solids.

Total particulate emission results (cyclone, front half wash, filter, back half) from the cyclone exhaust averaged 0.612 pounds per ton of coal with 90% less than 10 microns in size. Emissions from the scrubber exhaust are not presented due to questions concerning the "representativeness" of the slip stream.

PARTICULATE COMPARISON

Particulate data from Lorain, DOFASCO and EBV are compared in Table 10. The EPA Method 5 particulate emission rate (back half excluded) was found to correlate closely with the water quality, in particular, the total dissolved solids content. The DOFASCO river water quench emission data can be deduced from the Lorain data by comparing the TDS levels in the quench water and noting that none of the baffles in the DOFASCO tower arrangement were missing. The considerably higher back half catch on the EBV pressure quench is hypothesized to be attributed to differences in the physical-chemical nature of the processes, i.e., superheated steam aerosol (no air infiltration) at 280-400°F in the pressure quencher versus an air-steam exhaust at approximately 170°F in ambient quench systems. Coal sulfur and ash contents during each of the test programs were comparable, averaging approximately 1% and 7%, respectively.

DRY QUENCHING AS AN ALTERNATIVE PROCESS

Many complex problems are generated by most of the wet quenching systems. In addition to air and water pollution problems, coke quality degeneration and loss of usable coke are also associated with the operation. Furthermore, substantial energy is wasted during the process. Dry quenching provides a different approach to the problems associated with wet quenching (see Figure 12).

Dry quenching of incandescent coke after it has been pushed from the coking ovens is a proven, reliable process that is presently being used in several industrialized countries. Foremost among dry quenching's advantages are: (1) virtual elimination of air pollutants emitted during quenching; (2) elimination of potential water pollution associated with wet quenching; (3) improvements in the working environment; (4) saving substantial amounts of energy in usable forms; (5) producing more usable coke that is superior to wet-quenched coke. By continuously circulating inert gases through a cooling chamber that contains hot coke, dry quenching recovers waste-heat energy that can be used to produce steam, to produce electricity, to preheat combustion air, to preheat coal, to dry coal, and to preheat feed water supplied to fuel-fired boilers.

Dry quenching uses inert gases as a medium to collect heat from incandescent coke and to transport that heat to waste-heat boilers. Heat transfer from the coke to the inert gases is achieved by direct contact of the gases with the coke. Inert gases used to cool the coke and to transfer the heat are formed from an initial intake of air. Oxygen contained in the initial intake of air reacts with the hot coke to form CO_2. Except for the periodic introduction of hot coke, dry quenching is a closed cycle operation. The same gases are continuously circulated through the system. Consequently, the composition of the circulating gases does not fluctuate widely. Because oxygen is almost completely absent from the quenching medium, the danger of explosion is minimized. Nevertheless, explosion precaution procedures (e.g., pressure relief doors) are taken and the composition of the circulating gases continuously monitored.

The disadvantages of dry quenching include:

1. New equipment for dry quenching - with no reduction for equivalent conventional steam producing equipment - has a higher capital cost than wet quenching equipment.

2. Dry quenching facilities present potential explosion hazards somewhat comparable to those associated with pulverized coal boilers or with gas or oil steam generators. Reliance on automatic sequencing, monitoring, feedback, and purging systems help to minimize the hazards.

3. Dry quenched coke is inherently dustier at screening stations and during transport than wet quenched coke. This dustiness may require the installation of additional fugitive dust control equipment or measures.

CONCLUSIONS

The research performed thus far on coke quench tower emissions has yielded information concerning the physical and chemical composition of the emissions and the source of contaminants.

Contaminants found to be present in the quench tower plume include:

- Particulate
- Various gases (sulfur dioxide, phenol, ammonia, cyanide)
- Organic compounds (including 53 identified species, 7 of which were found in significant quantities to be considered a potential health hazard.)

The physical characteristics of these substances are as follows:

- Most of the particulate is relatively small in size (less than 10 microns)
- Most of the organic species are either gaseous or associated with particulates below 0.3 micron.

The primary source of the particulate, gases, and organics in quench tower emissions is contaminated quench water. Specifically:

- Particulate, gaseous, and organic matter emissions increase substantially when contaminated quench make-up water is used.
- The quantity of organic matter increases when green coke is being quenched.
- Pollutant reduction can also be achieved by minimizing or eliminating the oil used for oven density controls.

Total particulate emission levels on the order of 0.3 - 0.5 lb/ton of coal (front plus back half catches) are believed to be the best achievable from a conventional, well designed, properly baffled quench tower using relatively clean make-up water. By operating within the constraints of a natural draft system, only limited increases in collection efficiency are believed possible. To achieve any additional significant emission reductions, the utilization of expensive add-on hardware will be required.

The use of a pressure quench system has a number of advantages:

1. The hot car is deep enough to accept the full load of incandescent coke without moving. This allows a sealed connection to control push emissions.

2. Coke moisture is uniform and can be precisely adjusted.
3. The quench emissions are carried in a controlled flow of steam to whatever control devices are required.
4. Energy recovery from this pressurized steam flow is potentially available and could lead to a closed system with minimal emissions.
5. The volume of quench emissions is substantially less than in a conventional quench tower, because no air dilutes the steam from the coke bed.
6. No significant water pollution.

In particular, should quench tower emissions be severely restricted by EPA, advantages (3) and (5) become most attractive from a control viewpoint.

Other alternatives for emission reduction would require significant changes in the quench process. Dry quenching is one such example. Characteristics of the dry quenching process that are attractive include: substantial reduction of air pollution caused by coke quenching; curtailment of air pollution - especially soots and tarry smoke particles - during the hot coke push and during transportation to the quench tower; elimination of water pollution associated with wet quenching and improvements in the working environment and the surrounding community.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Bernard Bloom, Carl Edlund, Robert V. Hendriks, and R.M. Statnick of the U.S. Environmental Protection Agency for their role in the execution of the Lorain test programs. The Lorain work was supported by U.S. EPA Office of Enforcement under Contracts 68-01-3161 and 68-01-4138 and Industrial Environmental Research Laboratory (IERL) under Contracts 68-02-1401 and 68-02-2819.

Appreciation is also expressed to Gerry Ertel of DOFASCO and J.G. Riecker of Hartung, Kuhn Company for information presented in this paper.

The assistance of Julie L. Rudolph and Carl E. Reichsteiner of Arthur D. Little, Inc. in providing the organic analytical data for the Lorain work is gratefully acknowledged.

REFERENCES

1. Sidlow, A.F., "Source Test Report, Kaiser Steel Plant, Fontana, California", San Bernardino County Air Pollution Control District, February 29, 1972.

2. Memorandum from Robert A. Armbrust, Region IX, New York State Department of Environmental Conservation, to Bernard Bloom, Division of Stationary Source Enforcement, Office of Enforcement, U.S. E.P.A., November 6, 1975.

3. Buonicore, A.J. et. al., "Characterization Program for Coke Quench Tower Emissions," APCA Specialty Conference, Control of Air Emissions from Coke Plants, Pittsburgh, Pennsylvania, Proceedings, 126-143 (April 1979).

4. Laube, A.H., Jeffrey, J., Edlund, C., Particulate Sampling Techniques for a Coke Quench Tower, APCA Annual Meeting, Toronto, Canada, June 1977.

5. Laube, A.H., Jeffrey, J., and Sommerer, D., Evaluation of Quench Tower Emission Part II - Draft Report, Contract No. 68-01-4138, Task No. 3, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

6. Laube, A.H., Drummond, B.A., Coke Quench Tower Emission Testing Program - Draft Report, Contract No. 68-02-2819, Tast No. 1, U.S. Environmental Protection Agency, Research Triangle Park, NC, February, 1979.

7. Hendriks, R.V., et.al., "Organic Air Emissions from Coke Quench Towers," Paper No. 79-39.1, 72nd Annual Meeting of the Air Pollution Control Association, Cincinnati, Ohio (June 1979).

8. Rudolph, J.L. and Rechsteiner, C.E., Analysis of Samples from Coke Quench Tower Emissions, Cambridge, Massachusetts, Arthur D. Little, Inc., November 1978.

9. Cleland, J.G. and Kingsbury, G.L., Multimedia Environmental Goals for Environmental Assessment - Volume I, EPA-600/7-77-136b, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1977.

10. Schalit, L.M. and Wolfe, K.J., SAM/IA:A Rapid Screening Method for Environmental Assessment of Fossil Energy Process Effluents, EPA-600/7- 8-015, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1978.

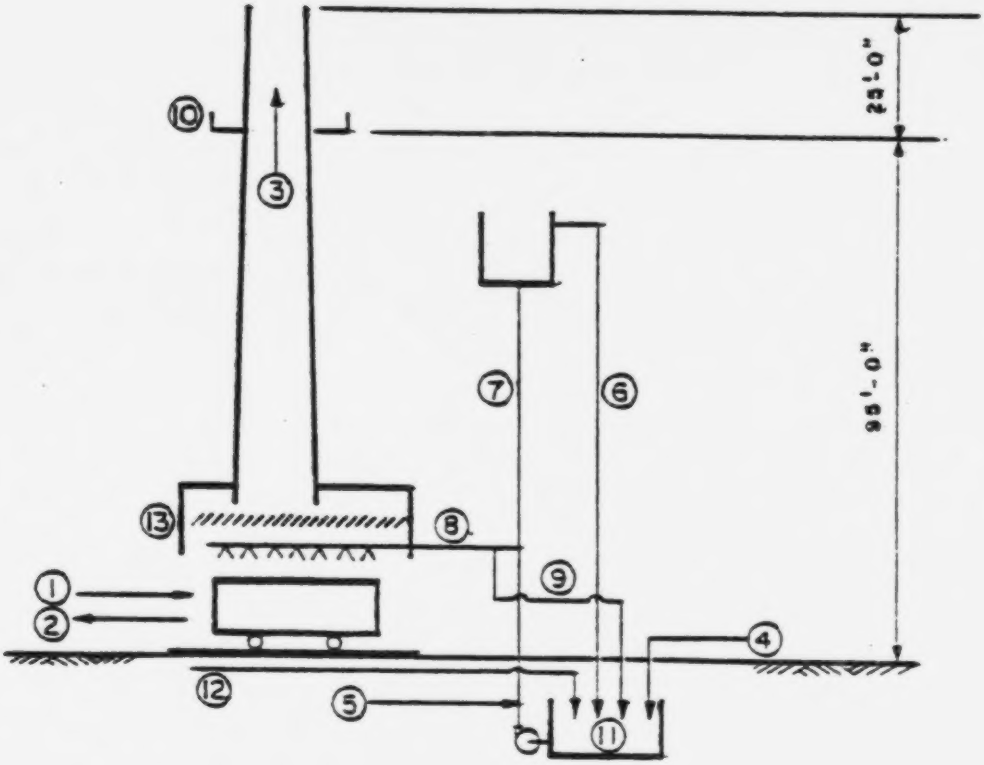
11. Particulate Polycyclic Organic Matter, National Academy of Sciences, Washington, DC, 1972, pp 4-14.

REFERENCES (continued)

12. Ertel, G.L., "Quench Tower Particulate Emissions," APCA Specialty Conference, Control of Air Emissions From Coke Plants, Pittsburgh, Pennsylvania, Proceedings, 114-125 (April 1979).

13. Buonicore, A.J., et.al., "Pressurized Quenching of Coke at Erin, Germany", Sixth National Conference on Energy and the Environment, American Institute of Chemical Engineers, Pittsburgh, Pennsylvania (May 1979).

14. Linsky, B. et.al., "Dry Coke Quenching, Air Pollution and Energy: A Status Report", J. APCA, Vol. 25, No. 9, 918-924 (1975).



① INCANDESCENT COKE
② QUENCHED COKE
③ EXHAUST GASES
④ CONTAMINATED WATER
⑤ SERVICE WATER
⑥ HEAD TANK - OVERFLOW
⑦ HEAD TANK - STAND PIPE
⑧ NOZZLE HEADER
⑨ NOZZLE HEADER DRAIN
⑩ EMISSIONS TESTING STATION
⑪ SUMP
⑫ RETURN DRAIN DITCH
⑬ BAFFLES

Quench Tower

Figure 1

FIGURE 2
BAFFLED SECTION OF QUENCH TOWER

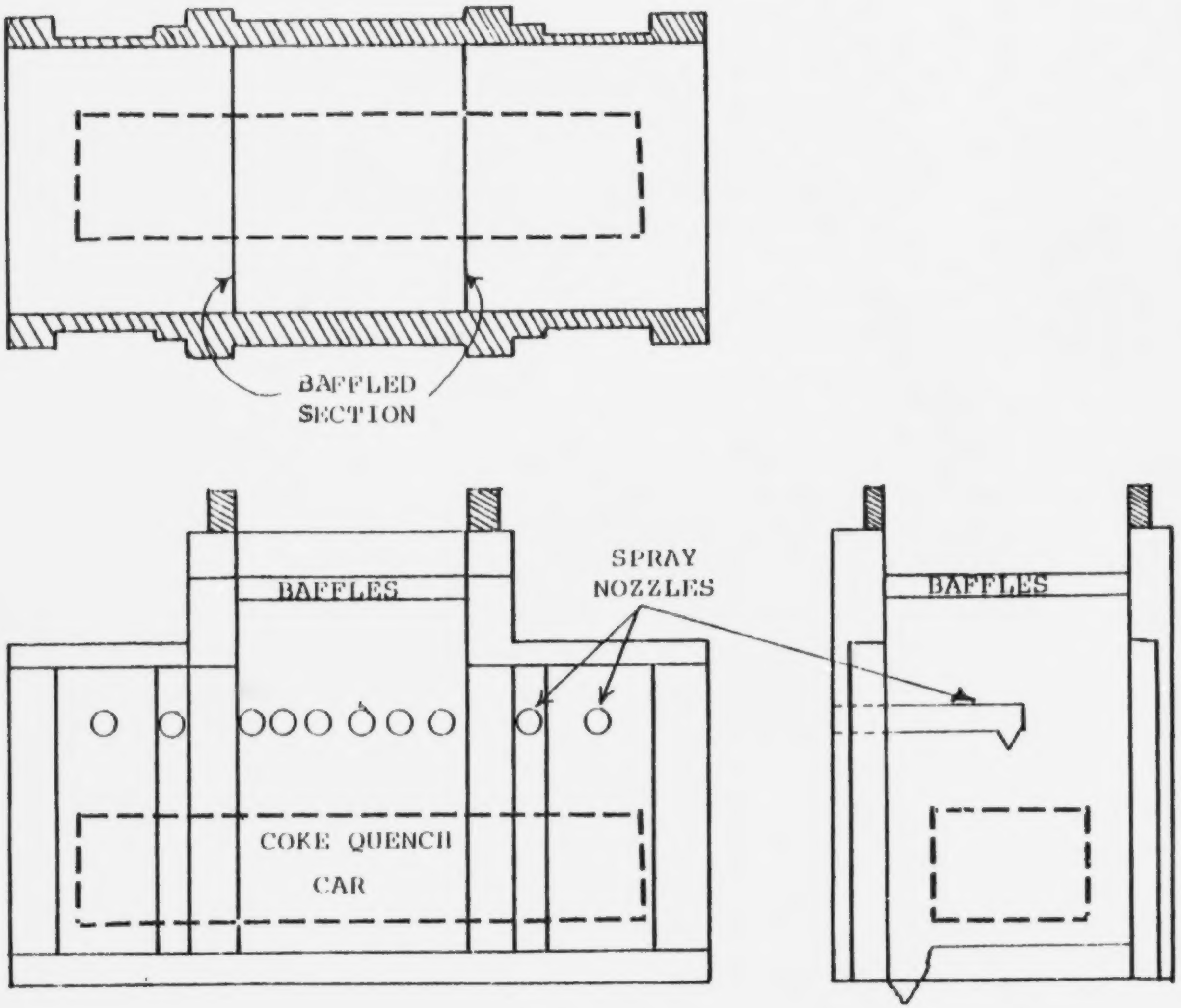
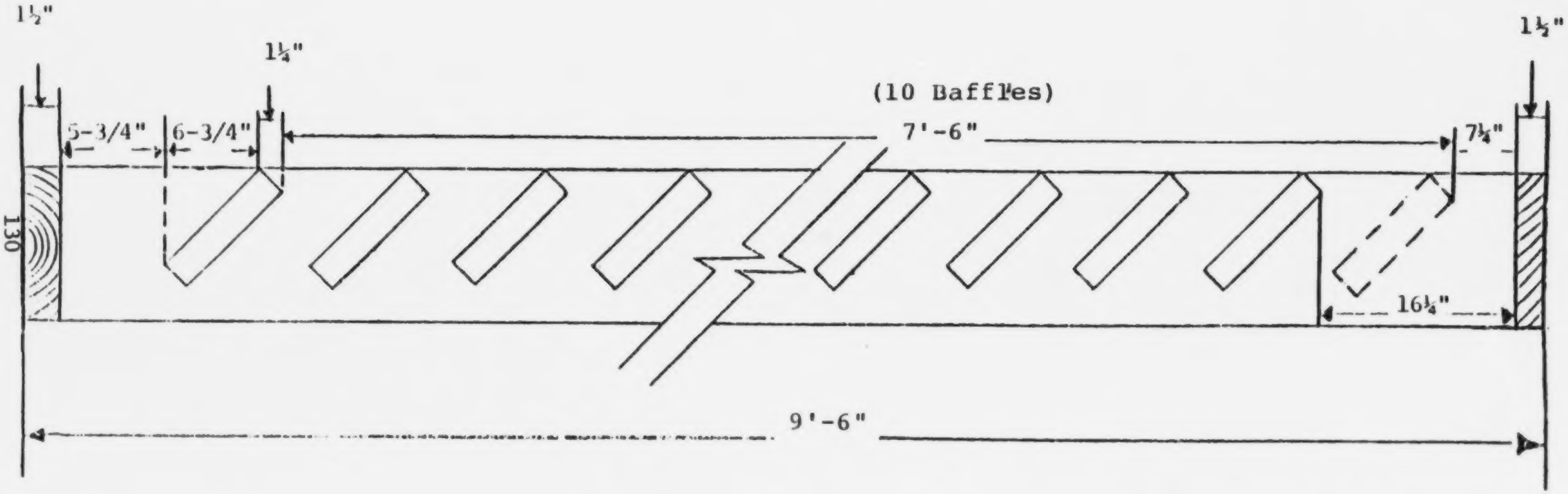

BAFFLED
SECTION
SPRAY
NOZZLES
BAFFLES
BAFFLES
COKE QUENCH
CAR

Figure 3

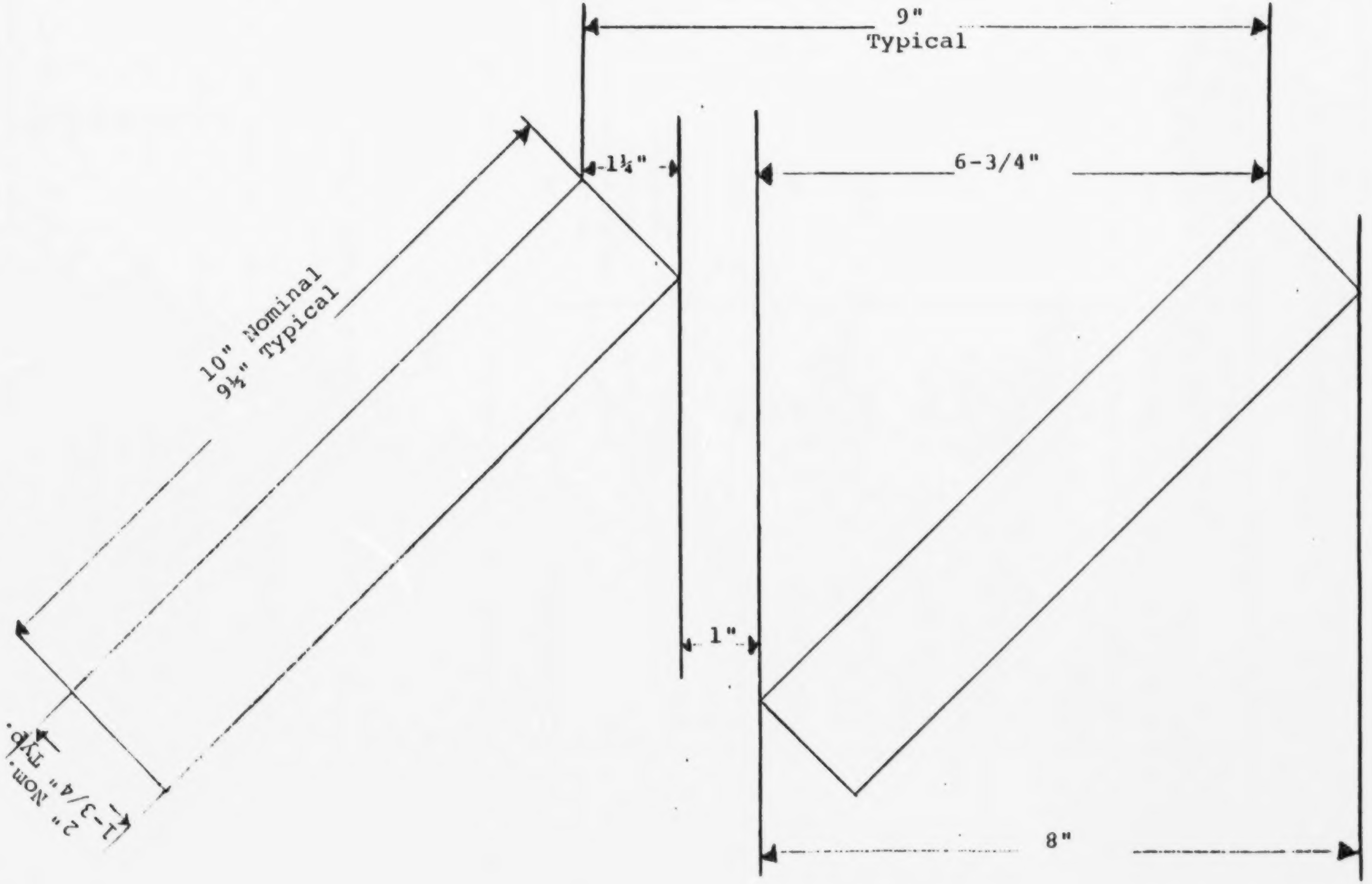
DETAILS OF BAFFLES


1½"
1¼"
(10 Baffles)
1½"
5-3/4"
6-3/4"
7'-6"
7¼"
16¼"
9'-6"

Six sections installed
each section 6'-3½" x 9'-0" overall
6'-0½" x 9'-3" inside

FIGURE 4

OPEN AREA BETWEEN BAFFLES


9"
Typical
1¼"
6-3/4"
10" Nominal
9½" Typical
1"
2" Nom.
1-3/4" Typ.
8"

DOFASCO'S
COKE PLANT QUENCH TOWERS DATA

	COKE PLANT NO. 1 BATTERIES NO. 1,2,3	COKE PLANT NO. 2 BATTERIES NO. 4,5	COKE PLANT NO. 3 BATTERY NO. 6
NO. OF OVENS	105	108	35
OVEN SIZE (Length x width x height)	40'-6" x 17" x 13'	40'-6" x 17" x 13'	48'-5½" x 16 ¼' x 20'
COAL CHARGED PER OVEN – TONS	16	16	30
COKING TIME – HR.	17.9	17.81	14.0(Min)
COKE QUENCHED PER OVEN – TONS	11	11	21
COKE QUENCHED PER DAY – TONS	1,560	1,591	1,343
QUENCH TOWER HEIGHT – FT.	60	56.51	110.25
QUENCH TOWER OUTLET AREA - FT^2	867	652	1,800
MIST ELIMINATOR	PACKING 18 - 24" OF 3" PLASTIC PALL RINGS	BAFFLES 1 x 4" SLATS 2 ROWS AT 20° INCLINED TO VERTICAL	BAFFLES 1 x 4" SLATS 4 ROWS AT 20° INCLINED TO VERTICAL
WATER/QUENCH USG	5,000	5,000	9,000

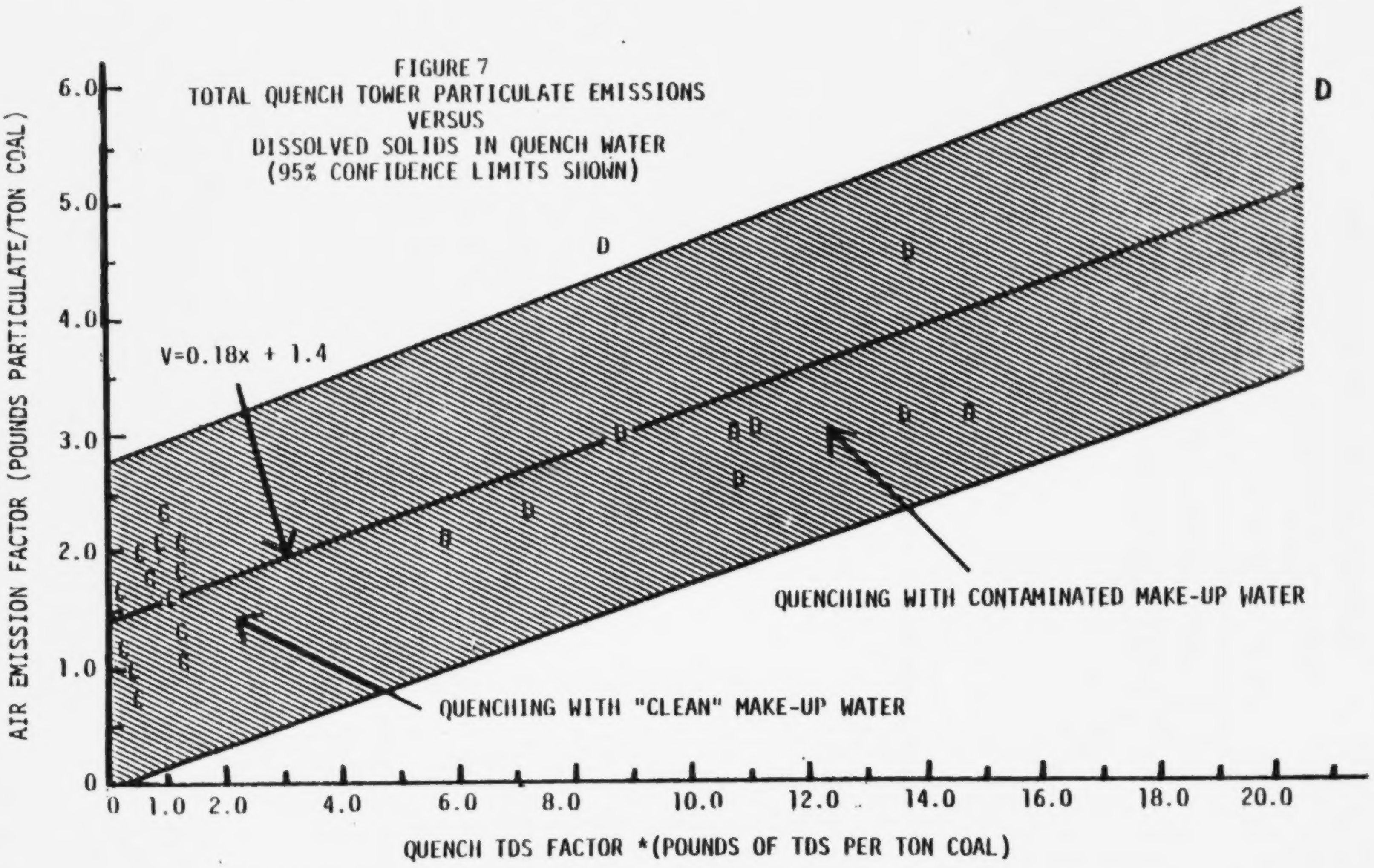
FIGURE NO 5

DOFASCO'S NO. 2 COKE PLANT
QUENCHING CYCLE

STEPS	TOTAL TIME FROM START OF CYCLE (sec.)
(1) QUENCH CAR IN TOWER	0
(2) WATER SPRAYS ON	10
(3) WATER SPRAYS OFF	55
(4) WATER SPRAYS ON	75
(5) WATER SPRAYS OFF	105
(6) QUENCH CAR OUT OF TOWER	130

FIGURE NO 6

FIGURE 7
TOTAL QUENCH TOWER PARTICULATE EMISSIONS
VERSUS
DISSOLVED SOLIDS IN QUENCH WATER
(95% CONFIDENCE LIMITS SHOWN)



*PRODUCT OF TDS CONCENTRATION AND AMOUNT OF WATER EJECTED FROM THE TOWER

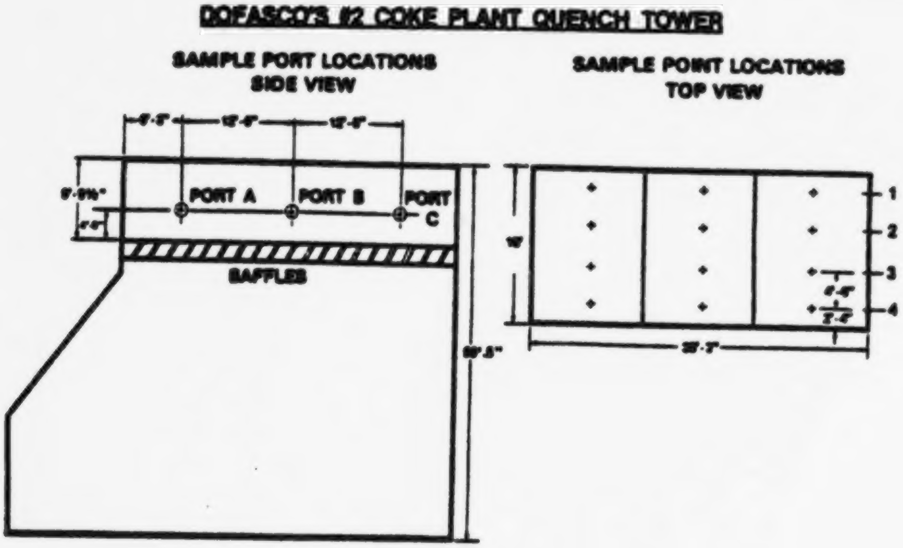

DOFASCO'S #2 COKE PLANT QUENCH TOWER
SAMPLE PORT LOCATIONS
SIDE VIEW
SAMPLE POINT LOCATIONS
TOP VIEW
12'-6"
12'-6"
PORT A
PORT B
PORT
C
BAFFLES
10'
1
2
3
4

Fig. 8

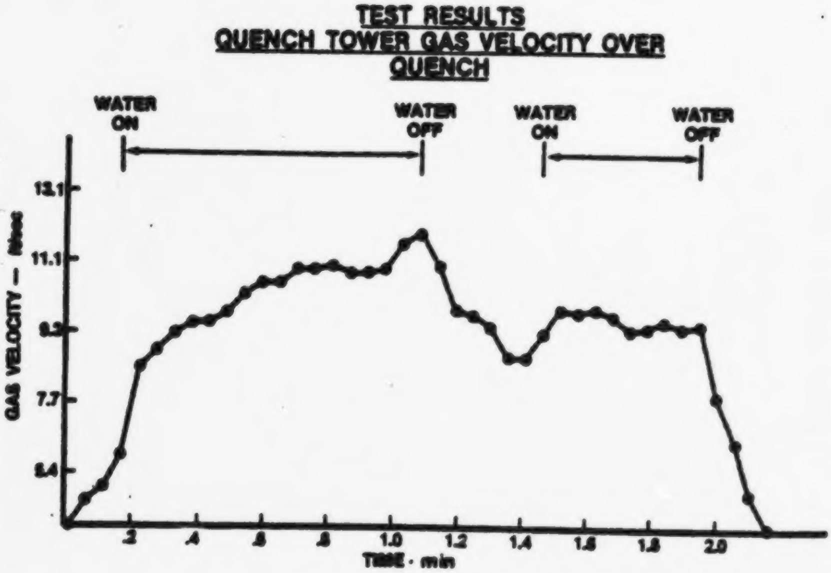

TEST RESULTS
QUENCH TOWER GAS VELOCITY OVER
QUENCH
WATER
ON
WATER
OFF
WATER
ON
WATER
OFF
GAS VELOCITY — ft/sec
13.1
11.1
9.2
7.7
5.4
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME · min

Fig. 9

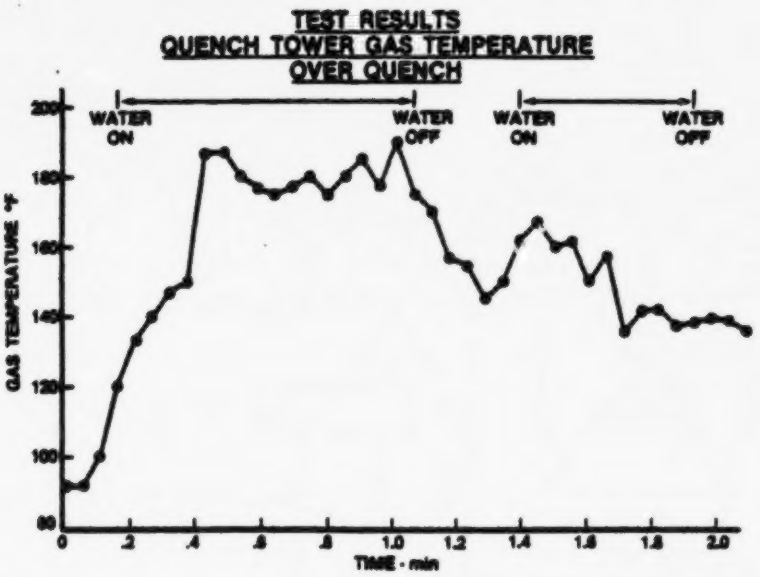
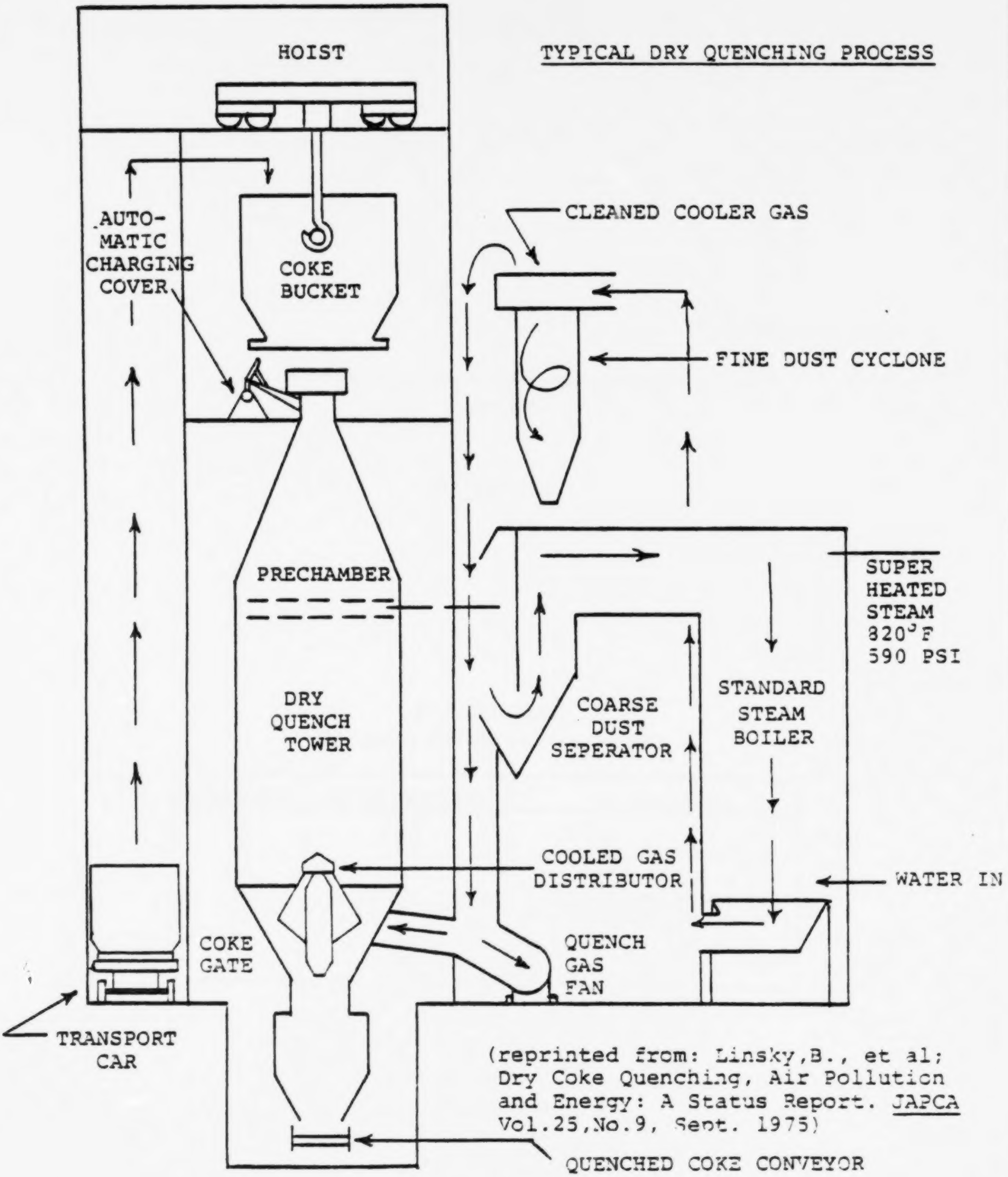


Figure 10

TEST RESULTS
QUENCH SPRAY WATER ANALYSIS

ANALYSIS ppm	RECYCLED WATER	BAY WATER
pH	7.6	8.0
SUSPENDED SOLIDS	265	19
TOTAL DISSOLVED SOLIDS	327	313
TOTAL ORGANIC CARBON	8	7
AMMONIA	.6	.6
CHLORIDE	170	55
SULFATE	53	53

Figure 11


HOIST
AUTO-MATIC CHARGING COVER
COKE BUCKET
CLEANED COOLER GAS
FINE DUST CYCLONE
PRECHAMBER
SUPER HEATED STEAM 820°F 590 PSI
DRY QUENCH TOWER
COARSE DUST SEPERATOR
STANDARD STEAM BOILER
COOLED GAS DISTRIBUTOR
WATER IN
COKE GATE
QUENCH GAS FAN
TRANSPORT CAR
QUENCHED COKE CONVEYOR

TYPICAL DRY QUENCHING PROCESS

(reprinted from: Linsky, B., et al; Dry Coke Quenching, Air Pollution and Energy: A Status Report. JAPCA Vol.25, No.9, Sept. 1975)

Figure 12

Table 1 - PARTICULATE TEST RESULTS (LORAIN 1976)

Parameter	Clean Water	Contaminated Water
Flow Conditions (Average)		
% Isokinetic	99.0	99.4
Flow Rate, DSCFM	190,700	183,300
% Moisture by Wt.	25.0	24.7
Particulate Emissions, lb/ton of coal		
Cyclone	0.28	1.17
Probe	1.16	1.15
Filter	0.02	0.45
Total Front Half	1.46	2.77
Total Back Half	0.16	0.81
Totals	1.62	3.58

Table 2 - QUENCH WATER CONTAMINANT CONCENTRATIONS (LORAIN 1976)

CONTAMINANT	CLEAN WATER mg/l	CLEAN WATER lb/ton of coal	CONTAMINATED WATER mg/l	CONTAMINATED WATER lb/ton of coal
TOTAL DISSOLVED SOLIDS				
Sprayed on Coke	1050	6.8	9850	64
Returned to Sump	1040	5.5	9670	52
Make-Up Water	520	0.64	5370	6.6
TOTAL SUSPENDED SOLIDS				
Sprayed on Coke	60	0.38	165	1.0
Returned to Sump	270	1.4	340	1.8
Make-Up Water	2.5	0.003	140	0.17

Table 3 - GASEOUS TEST RESULTS (LORAIN 1976) LB/TON OF COAL

COMPOUND	CLEAN WATER	CONTAMINATED WATER
Sulfur Dioxide	0.0053	0.46
Phenol	0.0038	0.22
Ammonia	0.026	0.33
Cyanide	0.0023	0.01

Table 4 - COMPARISON WITH CONTAMINANT LEVEL IN STACK EMISSIONS AND QUENCH WATER-LB/TON OF COAL (LORAIN 1976)

QUENCH WATER CONDITION	COMPOUND	GASEOUS EMISSIONS	QUENCH WATER CONTAMINANT LEVEL
Clean	Phenol	0.0038	0.0045
Clean	Ammonia	0.026	0.13
Clean	Cyanide	0.0023	0.0015
Contaminated	Phenol	0.22	0.21
Contaminated	Ammonia	0.33	0.78
Contaminated	Cyanide	0.01	0.055

Table 5 - TOTAL ORGANIC EMISSIONS (LORAIN 1976)

TYPES OF ORGANIC COMPOUNDS	CLEAN WATER				CONTAMINATED WATER			
	STACK EMISSIONS (1)		WATER (COMPOSITE)		STACK EMISSIONS		INLET WATER	
	lb/ton of coal	mg/m^3	lb/ton of coal	mg/l	lb/ton of coal	mg/m^3	lb/ton of coal	mg/l
ALIPHATIC HYDROCARBONS	1.72	735	0.008	1.2	0.04	14	0.008	0.5
AROMATIC HYDROCARBONS	N/A	N/A	-	-	-	-	0.008	0.9
NON-AROMATIC HETEROCARBONS	-	-	N/A	N/A	0.008	2	-	-
AROMATIC HETEROCARBONS	5.63	2408	0.03	5.4	0.68	259	0.57	98.3
ALDEHYDES, ESTERS, CARBOXILIC ACIDS, ACRYLATE POLYMERS	0.504	213	0.02	3.9	0.25	95	0.29	50.4
KETONES, AMINE SALTS, PHOSPHINES, ISOTHIOCYANATE	0.107	44	0.008	0.3	0.08	33	0.008	1.1
TOTALS	7.96	3400	0.07	10.8	1.06	403	0.88	151.2

(1) Average of 2 tests
 - Not Detected
N/A Detected but weight not available

Table 6 - POLYNUCLEAR AROMATIC HYDROCARBON DETERMINATIONS (LORAIN 1976)

	Contaminated Water				Clean Water			
	Stack Emissions		Inlet Water		Stack Emissions*		Water (Composite)	
	lbs/ton of coal ($x10^{-5}$)	µg/m³	lbs/ton of coal ($x10^{-5}$)	µg/l	lbs/ton of coal ($x10^{-5}$)	µg/m³	lbs/ton of coal ($x10^{-5}$)	µg/l
Anthracene/Phenanthrene	0.24	0.9	0.26	0.5	0.13	0.6	0.03	0.05
Methyl Anthracenes	0.10	0.4	0.07	0.1	0.07	0.3	0.02	0.04
Fluoranthene	0.12	0.5	0.28	0.5	0.07	0.3	0.03	0.05
Pyrene	0.09	0.4	0.16	0.3	0.05	0.2	0.02	0.04
Methyl Pyrene/ Fluoranthene	0.07	0.3	0.10	0.2	0.04	0.2	0.02	0.04
Benzo(c)phenanthrene	0.07	0.3	0.06	0.1	0.04	0.2		
Chrysene/Benz(a)-anthracene	0.10	0.4	0.17	0.3	0.05	0.2	0.03	0.05
Methyl chrysenes			0.09	0.2	0.004	0.2		
Dimethyl benz(a)-anthracene					0.05	0.2		
Benzo Fluoranthenes			0.12	0.2				
Benz(a)pyrene			0.02	0.04				
Benz(e)pyrene			0.04	0.08				
Indene (1,2,3-cd) pyrene			0.04	0.06				
Total	0.79	3.2	1.4	2.58	0.50	2.4	0.15	0.27

* Average of two tests

Table 7 - POLYNUCLEAR AROMATIC HYDROCARBONS (LORAIN 1977)
(AVERAGE LB/TON OF COAL)

Clean Water	
• Low Greenness	0.000838
• High Greenness	0.00234
Contaminated Water	0.0642

Table 8 - QUENCH WATER ANALYSIS - LB/TON OF COAL (LORAIN 1977)

	Clean Service Water	Water Inlet to Nozzle	Contaminated Flushing Liquor	Water Inlet to Nozzle
Total PAH	0.000162	0.000065	0.0334	0.0122
Total Polar Compounds (not including phthalates)	0.0000036	----	0.0981	0.2074

Table 9 - BENZO(A)PYRENE ANALYSIS - LB/TON OF COAL (LORAIN 1977)

Clean Water	.000038
Contaminated Water	.000162

TABLE 10

PARTICULATE EMISSION DATA COMPARISON

Particulate Emission Data (lb/ton of coal)

	Lorain-1976		Lorain-1977		DOFASCO		EBV
	River Water	Contaminated Water	River Water	Contaminated Water	River Water	River Water + Baffle Sprays	City Water
Cyclone	0.28	1.17	0.669	1.774	0.028	0.022	0.076
Front Half Washings	1.168	1.15	0.148	0.193	0.180	0.181	0.046
Filter	0.016	0.45	0.634	0.314	0.052	0.010	0.070
Subtotal	1.464	2.77	1.451	2.281	0.260	0.213	0.192
Back Half	0.156	0.81	---	---	0.204	0.155	0.420
Subtotal	0.156	0.81	---	---	0.204	0.155	0.420
Total	1.620	3.58	---	---	0.464	0.368	0.612
Quench Water Quality (mg/l)							
TDS	1050	9850	---	---	327	327	253
TSS	60	165	---	---	265	265	3

COKE BATTERY ENVIRONMENTAL CONTROL
COST-EFFECTIVENESS

by

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ABSTRACT

A computerized optimization model has been developed to examine the cost-effectiveness of alternative emission control strategies for coke plants. The model calculates the lowest cost mix of controls to meet a given overall level of emissions for a given air pollutant, and also calculates the lowest overall emissions that can be achieved for a given cost. The data base is uncoupled from the model so that it can be updated as new or improved data become available. The present emission data base contains emission factors for four air pollutants--particulate matter, benzene soluble organics, benzene, and benzo-a-pyrene--for 14 coke plant sources. The plant data base encompasses 216 batteries in 58 plants. The cost data base contains capital and annualized cost functions for 41 control techniques, but as many as 8 control options can be accommodated for each source. The data base can be subdivided to enable examination of other factors, such as old versus new batteries or large versus small batteries. The optimization can be focused on either capital cost or annualized cost.

COKE BATTERY ENVIRONMENTAL CONTROL COST-EFFECTIVENESS

INTRODUCTION

The characterization and control of coke oven emissions have been of intense interest and study for over 10 years. Originally, focus was directed primarily toward visible emissions because most coke oven emissions are fugitive in nature. As data became available on the complex chemical structure and health effects of the emissions, attention shifted to the organic components. Because environmental control of coke oven operations requires the evaluation of numerous options, and because technology and new information are continually developing, the U.S. Environmental Protection Agency (EPA) contracted PEDCo Environmental, Inc., to develop a computer model that could calculate the cost and emission levels for any combination of controls. Even more important, the model should be able to calculate the lowest cost mix of controls to meet a given overall level of emissions, or alternately the lowest overall emission level that can be attained at a given total cost. Either capital cost or annualized cost can be the focus of optimization.

Intended as an engineering tool for evaluating control strategies on a continuing basis, the model operates on the EPA computer at the National Computation Center in Research Triangle Park, North Carolina. It accommodates data on four pollutants: particulate matter (defined herein as front-half-Method 5), benzene soluble organics (BSO), benzo-a-pyrene (BaP), and benzene. The model includes the coke oven battery, the coal storage and preparation steps, the quenching and coke screening operations, and the byproduct plant. It addresses both conventional batteries and preheated coal batteries. The model contains very limited information regarding byproduct operations, but studies are under way by the EPA to characterize the emissions from this source.

MODEL STRUCTURE

The model consists of two distinct parts, the mathematical structure and the data base. It must be recognized that the present data base is only intended to represent a starting point. It is designed to be easily updated because new data, especially for emission factors, are continually being developed.

Dataset 1: Emission Factors

Fourteen air emission sources and four pollutants are presently considered, as shown in Table 1. (Note that two sources have alternate factors.) The term "uncontrolled" is not easily defined for coke ovens, but for our purposes it represents the conditions existing at the majority of batteries in the late 1960's. Although this definition still leaves much room for judgment, it eliminates the totally uncontrolled conditions that would prevail if a coking process were operated with no concern whatever for emissions.

Emissions from most of the sources are fugitive in nature, and do not lend themselves readily to Method 5 sampling techniques. Two commonly used techniques are single-point sampling with a Method 5 train and High-Vol sampling. Isokinetic conditions are often difficult to achieve, and sample results are generally corrected to reflect anisokinetic sampling.

The use of test data to develop emission factors requires several assumptions. The first is that the results of the test are representative of the emissions found at the entire battery; the second is that the emissions from the tested battery are representative of the industry as a whole. Clearly, notable exceptions will be found to these assumptions, and the emission data used herein must be treated with appropriate caution. In the case of door emission tests, for example, results obtained on only one door do not indicate that all the doors leak similarly. Further, the sampling results from a single green push do not necessarily represent all the coke pushes at that battery.

The definition of particulate matter is important in dealing with coke oven emissions. Generally, a reference to particulate catch means the front half or filterable portion of a Method 5 sample train (or its equivalent). Total suspended particulate (TSP), however, implies both the front and back

TABLE 1. SUMMARY OF UNCONTROLLED EMISSION FACTORS (lb/ton of coal)

Source code No.	Emission source	Pollutant			
		TSP[a]	BSO	BaP	Benzene
1	Larry car charge (wet coal)	1.0[b]	1.1[b]	0.002[c]	0.5[d]
2	Coke pushing[e]	2.0[f]	0.08[f]	4×10^{-5}[f]	0.006[f]
3	Quench, clean water	1.7[f,g]	1.7×10^{-3}[b]	1.4×10^{-4}[b]	3×10^{-5}[c]
4	Doors	0.4[b]	0.5[b]	0.003[b]	0.02[b]
5	Topside leaks	0.2[d]	0.25[d]	0.001[d]	0.005[d]
6	Combustion stack (old)[h]	1.3[d]	0.006[d]	6×10^{-5}[d]	0[d]
7	Coke handling	1.0[d]	0[d]	0[d]	0[d]
8	Coal preheat	7.05[b]	1.05[b]	3.9×10^{-4}[c]	0.014[c]
9	Coal preparation	0.5[d]	0[d]	0[d]	0[d]
10	Coal storage	0.15[d]	0[d]	0[d]	0[d]
11	Pipeline charge (dry coal)	0.016[d]	0.019[d]	3.5×10^{-5}[d]	0.008[d]
12	Redler conveyor (dry coal)	0.010[d]	0.006[d]	1.1×10^{-5}[d]	0.0049[d]
13	Hot larry car (dry coal)	0.017[d]	0.019[d]	3.5×10^{-5}[d]	0.008[d]
14	Byproduct	0[c]	0.3[c]	0[c]	0.2[c]
15	Combustion stack (new)[h]	0.13[d]	6×10^{-4}[d]	6×10^{-6}[d]	0[d]
16	Quench, dirty water	3.2[f,g]	6.4×10^{-3}[b]	3.1×10^{-4}[b]	2.6×10^{-4}[c]

[a] All TSP values derived from the front half of Method 5 or an equivalent method.

[b] One or more tests conducted, moderate confidence in accuracy.

[c] Test data available but inconclusive, low confidence in accuracy.

[d] No test data available. Emission factor calculated from other sources, very low confidence in accuracy.

[e] For dry coal charging, lower values may be appropriate (see text).

[f] Several tests conducted, good correlation between data, good confidence in numerical accuracy.

[g] Two cases are considered: "clean" water and "dirty" water. Existing data are used to select the appropriate emission factor.

[h] Emissions depend on the maintenance history and age of the battery. The term "new" designates a well maintained battery with effective patching and maintenance programs. The term "old" designates the opposite. The population is subdivided on the assumption that batteries under 15 years old are new and over 15 years old are old. This approach is questionable, but in the absence of site-specific data, it is a starting point. Sensitivity analysis can be used to investigate the significance of various assumptions.

half of a Method 5 test. The definition used must be consistent with the predicted control efficiencies, particularly when discussing TSP. It is likely that many of the particulate control devices would not "see" the organic particulate captured in the back half of the sampling train because it would be gaseous in form as it passed through the control device and would condense some time later.

Governed by these restraints, emission factors were developed for each of the four pollutants. To the extent possible, results from emission tests were used. When explicit data were unavailable, an attempt was made to derive an emission rate from other available information and assumptions. If an emission factor could not be developed by either of these approaches, an engineering estimate was made. The entire emission matrix had to be provided so that initial runs of the model could be completed. Where estimates have a broad confidence range, model runs can be made for various values to examine sensitivity.

Dataset 2: Cost Functions

All cost functions are expressed as $Y = AX^B$, where Y is annualized cost or capital cost in fourth quarter 1978 dollars, X is tons of annual coke capacity, and A and B are constants for the specific control technique. Capital and annualized cost functions are provided for both new and retrofit installations.

Table 2 lists the control options by source. The efficiencies shown are initial estimates only and are subject to change as new data become available. The model will accommodate as many as 8 control options for each source, but only a total of 41 are presently considered. Although control efficiency is discrete in some cases and continuous in others, discrete levels have been used in the model for simplification. As new control options are added or existing ones modified, the appropriate cost functions are added to Dataset 2. The A and B coefficients for some of the cost functions presently used in the model are shown in Table 3. Further examination of the cost functions for small batteries (below 100,000 tons of coke per year) is necessary to determine if the functions are accurate in this low range.

TABLE 2. CONTROL OPTIONS BY SOURCE

Source	Control option	Efficiency				Remarks
		TSP	BSO	BaP	Benzene	
Larry car charging	Modified car	30.0	80.0	80.0	80.0	
	New car	99.0	99.0	99.0	99.0	
	Retrofit second main + new car	99.5	99.5	99.5	99.5	
Coke pushing	Controlled coking	60.0	60.0	60.0	60.0	19.0 h avg. coking time vs. 17.5 h base
	Shed + ESP 95%	85.5	45.0	45.0	45.0	
	Shed + scrubber 95%	85.5	49.5	49.5	49.5	
	Enclosed car	88.2	54.0	36.0	54.0	
	Shed + ESP 99%	89.1	45.0	45.0	45.0	
	Shed + scrubber 99%	89.1	54.0	54.0	54.0	
Quenching clean water	Baffles	70.0	70.0	70.0	0.0	
	Diverted flow baffles	90.0	90.0	90.0	0.0	
	Dry quenching	98.0	99.0	99.0	99.0	Includes option 5 on source 2
Doors	Cleaning and maintenance	60.0	60.0	60.0	60.0	
	High pressure water cleaning	80.0	80.0	80.0	80.0	Includes door cleaning machine
	Door hood and scrubber 95%	88.5	78.0	78.0	65.0	
	Door hood + scrubber 98%	93.3	83.8	83.8	72.0	
Topside	Luting and cleaning	90.0	90.0	90.0	90.0	Not applicable to pipeline batteries
	Luting and maintenance	95.0	95.0	95.0	95.0	
	New lids and castings + luting and cleaning	97.0	97.0	97.0	97.0	
Combustion stack-old	Oven patching	80.0	80.0	80.0	80.0	
	Dry ESP 90%	90.0	50.0	50.0	50.0	
	Dry ESP 98%	98.0	60.0	60.0	60.0	
	Baghouse 98%	98.0	50.0	50.0	50.0	
Coke handling	Enclosures + baghouse 99%	89.1	NA	NA	NA	
Coal preheater	Scrubber-15 in.	95.0	60.0	60.0	50.0	
	Dry ESP 95%	95.0	45.0	45.0	45.0	
	Scrubber-30 in.	98.0	60.0	60.0	50.0	
	Dry ESP 99%	99.0	50.0	50.0	50.0	
Coal preparation	Enclosure and baghouse-99%	97.0	NA	NA	NA	
Coal storage yard	Water truck	60.0	NA	NA	NA	
	Unload sprays and water truck	75.0	NA	NA	NA	
	Coal pile sprays	90.0	NA	NA	NA	
Pipeline charging	Operation and maintenance	99.0	99.0	99.0	99.0	
Redler charging	Operation and maintenance	99.0	99.0	99.0	99.0	
Hot larry car charging	Operation and maintenance	99.0	99.0	99.0	99.0	
Byproduct plant	Maintenance	NA	80.0	80.0	80.0	
Combustion stack-new	Oven patching	80.0	80.0	80.0	80.0	
Quenching-dirty water	Baffles	70.0	35.0	35.0	0.0	
	Clean water + baffles	85.0	75.0	80.0	75.0	
	Diverted flow baffles + clean water	95.0	85.0	85.0	75.0	
	Dry quenching	99.0	99.0	99.0	99.0	Includes option 5 on source 2

NA - not applicable

TABLE 3. COST FUNCTION COEFFICIENTS FOR CONTROL OPTIONS[a]
(cost in fourth quarter 1978 dollars)

Source control option	Basis for X value	New Installation				Retrofit Installation			
		Capital cost		Annualized cost coefficient		Capital cost coefficient		Annualized cost coefficient	
		A	B	A	B	A	B	A	B
Wet coal charging	Battery								
Modified larry car		290,539.2	0.0250	227,751.9	0.0762	319,187.0	0.0251	230,194.8	0.0761
New larry car		2,784.7	0.4882	68,022.8	0.1934	3,064.5	0.4882	63,015.2	0.2014
New larry car & second main		326,894.4	0.1935	341,620.2	0.1117	293,877.1	0.2046	320,512.5	0.1178
Coke pushing	Battery								
Controlled coking		0	0	25.7	0.9593	0	0	25.7	0.9593
Shed and ESP, 95%		17,498.8	0.4228	3,177.5	0.4737	22,052.2	0.4141	3,659.2	0.4670
Shed and scrubber, 95%		25,028.5	0.4223	7,752.5	0.4439	30,128.9	0.4166	8,519.4	0.4403
Enclosed hot car		423,778.8	0.1938	70,214.2	0.2354	466,163.3	0.1938	76,212.7	0.2332
Shed and ESP, 99%		14,710.7	0.4422	2,907.6	0.4836	18,452.7	0.4337	3,345.8	0.4771
Shed and scrubber, 99%		23,357.7	0.4310	5,243.8	0.4823	28,061.2	0.4254	5,825.5	0.4776
Quenching, clean water	Plant								
Conventional baffles		1.7	0.8412	0.4	0.8750	2.1	0.8412	0.4	0.8707
Diverted flow baffles		82.6	0.7119	9.5	0.7714	107.5	0.7119	12.7	0.7621
Dry quenching[b]		771.8	0.7065	87.6	0.7683	848.9	0.7065	96.8	0.7651
Doors	Battery								
Cleaning and maintenance		0	0	804,801.2	0	0	0	804,801.2	0
High pressure water cleaning		414,499.8	0	876,701.5	0	414,499.8	0	876,701.5	0
Door hoods, scrubber, 95%		18,558.0	0.3453	954,615.0	0.0624	21,613.0	0.3487	880,426.2	0.0708
Door hoods, scrubber, 98%		21,562.1	0.3441	879,789.9	0.0715	25,298.2	0.3465	812,304.1	0.0800
Door hoods, scrubber, 95% one side		13,431.0	0.3409	106,371.0	0.0431	15,000.0	0.3443	998,158.0	0.0496
Door hoods, scrubber, 98% one side		11,682.0	0.3620	863,212.0	0.0614	13,625.0	0.3638	808,202.0	0.0682
Topside	Battery								
Luting and cleaning		0	0	264,900.1	0	0	0	264,900.1	0
Luting, cleaning, and maintenance		0	0	503,300.4	0	0	0	503,300.4	0
New lids, luting, and cleaning		81,100.0	0	300,799.9	0	105,399.9	0	304,299.8	0
Combustion stack, old	Battery								
Oven patching		0	0	503,300.4	0	0	0	503,300.4	0
Dry ESP, 90%		2,534.3	0.5283	5,373.4	0.3994	2,976.1	0.5306	5,061.8	0.4101
Dry ESP, 98%		2,609.3	0.5484	3,989.6	0.4333	3,085.1	0.5500	3,800.7	0.4440
Fabric filter, 98%		418.3	0.6518	551.5	0.5543	515.9	0.6504	546.8	0.5616

Dataset 3: Coke Oven Battery Data

This dataset provides a record of the following for each battery in the United States:

Company code
Date installed or date of last major rebuild
Number of ovens
Capacity, tons of coke/year
Type of charging used
Oven height
Number of collecting mains
Control equipment in place

Input of the battery data is arranged so that they can easily be updated. Although some of the data are estimated, most of the industry is correctly represented in the census; the aggregate costs calculated from the current data base should be representative exclusive of those cost increments that are highly site-specific.

Capacity is used as the variable in determining control costs. Certain costs, however, are not strictly a function of capacity. Shed cost, for example, is a function of oven height and number of ovens. In the case of quench towers, cost is proportional to the number of towers. It is assumed that one quench tower can handle up to 2500 tons of coke per day. For coal yards, coal preparation, coke processing, and byproduct plants, the model calculates costs for entire plants rather than individual batteries. Table 4 shows the relationship between key oven parameters used to translate capacity data into the physical size data needed to determine certain costs. For example, oven volume is the key parameter for sizing larry cars, and tons of coke per push is the key parameter for determining enclosed hot car cost. These relationships were used in calculating the cost functions for model input. Because most batteries fall into one of the three categories shown in Table 4, the use of capacity as the cost variable is reasonable.

Site-specific factors certainly affect cost. For example, the economy of scale gained by combining two or more adjacent batteries under a common control device has not been considered. Such site-specific factors are not

TABLE 4. RELATIONSHIPS OF SIZE AND OTHER PARAMETERS, COKE OVEN BATTERY

Basis: 50 ovens

Oven height, m	3	4	6
Oven volume, ft^3	540	720	1390
Tons coke/push	8.5	12.0	25.0
Without preheat			
Coking time, h	17.5	17.5	17.5
Pushes/day	68.6	68.6	68.6
Tons coke/yr[a]	213,000	300,000	626,000
With preheat			
Coking time, h	12.5	12.5	12.5
Pushes/day	96	96	96
Tons coke/yr[a]	296,000	420,000	876,000

[a] Directly proportional to number of ovens and inversely proportional to coking time.

considered at this time, but the model could be refined to do so. Additional factors more specific to individual batteries, such as the need to relocate existing facilities to make room for control equipment, could also be added to the model if site-specific information of this detail were available.

To evaluate projected growth (or decline) in the industry, the user may add battery data corresponding to the projected growth or delete battery data for projected retirements. The primary distinction between "new" and "existing" in the model is the use of new or retrofit cost functions.

In representing existing control at a plant, the exact control equipment may not be the same as that designated in the available control options. The user must, therefore, select the control option that most closely corresponds to the existing equipment or control program on the basis of efficiency. Alternatively, additional control options can be added to the model.

Costs are adjusted in the model in one of two ways:

1. Correcting total industry costs for those plants where some control is already in use.
2. Allowing the use of a control baseline (e.g., SIP) and considering only costs above this baseline.

As an example of the first case, assume Battery 1 has already installed a new larry car for stage charging and has good stage charging practice. The data for this battery would indicate these conditions, and the only costs calculated would be those for more efficient controls (if such exist). Tear-out costs for removal of existing controls are not considered in the present model.

If a control system is installed and does not correspond to one of the options in the model, it must be considered comparable to achieving a given level of control efficiency rather than equivalent to the specific hardware configuration. For this reason, the control options are ordered according to degree of efficiency. This permits the user to select the option that achieves the highest level considered appropriate.

In the control baseline case, the user establishes a base level of control below which costs are not considered. For example, if the baseline for charging control is modified larry cars for stage charging, costs will be considered only for options exceeding this level

Two "interactions" are recognized in the model:

> The use of shed control affects control of coke-side door emissions. If a shed and door hoods are selected, the door hoods are used only on the push side.
>
> The use of dry quenching affects control of pushing emissions because dry quenching utilizes an enclosed hot car. The cost of dry quenching also includes the cost of water treatment at those plants that would otherwise use dirty water for quenching.

MODEL FORMULATION

The first step in the model is the calculation of total industry control costs and emissions. Mathematical nomenclature has been defined as follows:

i = the emission source $(i = 1 \ldots I)$

j = the pollutant $(j = 1 \ldots J)$

k = the control technology $(k = 1 \ldots K)$

n = the specific battery $(n = 1 \ldots N)$

E = the annual emissions, in tons/year

C = the annualized cost (or capital cost)

e_{ijk} = the control efficiency

X_n = the capacity of battery n in tons of coke/year

U_{ij} = the uncontrolled emission factor in lb/ton of coal

Note that for some sources, such as coke handling, X_n actually represents capacity for all batteries in a given plant.

Then C_{ijkn} represents a specific dollar value calculated from the general cost function:

$$C_{ijkn} = A_{ijk} X_n^{B_{ijk}}$$

where A = y intercept, B = slope

Note that $C_{i1kn} = C_{i2kn} = C_{i3kn} = C_{i4kn}$

In other words, the cost of a specific control system does not vary by pollutant.

Similarly, $E_{ijkn} = [\frac{(100 - e_{ijk})}{100} (U_{ij}) (X_n/.7)] / 2000$

but $E_{i1kn} \neq E_{i2kn} \neq E_{i3kn} \neq E_{i4kn}$

The C and E matrices are calculated from the input datasets. Note that k = 1 will represent no additional control. Consequently, C_{ij1n} = zero by definition and

$$E_{ij1n} = [(U_{ij})(X_n/.7)] \div 2000$$

The total emission restriction (Mode 2) is entered as an overall percent efficiency, represented by R_j. This will be converted to ρj, an annual quantity, by the equation:

$$\rho j = (1 - \frac{R_j}{100}) \left(\sum_{n=1}^{N} \sum_{i=1}^{I} E_{ijn},\ k = 1 \right)$$

The total cost restriction (Mode 3) will be entered as a total dollar amount, T.

Finally, note that not all i exist for every n. The C and E matrices, therefore, are not full.

The next step is to compress the total C and E matrices to a total industry basis, i.e., to eliminate the n dimension. Let C' and E' represent the total industry:

$$C'_{ijk} = \sum_{n=1}^{N} C_{ijkn}$$

Again noting that $C'_{i1k} = C'_{i2k} = C'_{i3k} = C'_{i4k}$

Similarly,

$$E'_{ijk} = \sum_{n=1}^{N} E_{ijkn}$$

and $E'_{i1k} \neq E'_{i2k} \neq E'_{i3k} = E'_{i4k}$

Furthermore, E' can be treated as four separate matrices, E'_{ik} for j = 1, E'_{ik} for j = 2, etc.

The data are now reduced to two simple matrices,

C_{ik} and E_{ik} for each j

To find the optimum combination of controls, consider Mode 2, the restriction being total emissions, ρ_j, and the objective being to find lowest cost. Another matrix, Y, must now be introduced. The values of Y will be either one or zero. A one will indicate that a control option, k, is selected, and a zero will indicate that the control option is not selected. The Y matrix is a mathematical device to solve the optimization and has no significance from an engineering standpoint. For example,

let $Y_{ik} = Y_{14} = 1$

This means that Control Option 4 on Emission Source 1 is part of the optimum solution.

If this is so, then by definition all other Y's for source 1 are zero:

$Y_{11} = Y_{12} = Y_{13} = Y_{15} = Y_{16} = Y_{1k} = 0$

That is, a source can only be controlled by one option at a time. This integer device avoids the potential problem of finding optimum solutions that fall between discrete control systems. If all control systems had continuous cost-efficiency functions, a noninteger optimization could be used.

The statement of the problem in matrix form is, therefore:

Minimize ΣCY	for a given j
subject to $\Sigma Y = 1$	for all i
and $\Sigma EY \leq \rho$	for a given j
and $Y \geq 0$	for all i

In expanded form:

$$\text{minimize } C_{11}Y_{11} + C_{12}Y_{12} + \cdots\cdots\cdots C_{1k}Y_{1k}$$
$$+ C_{21}Y_{21} + C_{21}Y_{21} + \cdots\cdots\cdots C_{2k}Y_{2k}$$
$$+ \cdots\cdots\cdots\cdots\cdots\cdots C_{ik}Y_{ik}$$

$$\begin{array}{ll} \text{subject to } & Y_{11} + Y_{12} + Y_{13} + \ldots\ldots\ldots Y_{1k} = 1 \\ & Y_{21} + Y_{22} + Y_{23} + \ldots\ldots\ldots Y_{2k} = 1\text{, etc., for each source} \end{array}$$

$$\begin{array}{ll} \text{and: } & E_{11}Y_{11} + E_{12}Y_{12} + \ldots\ldots\ldots\ldots E_{1k}Y_{1k} \\ & + E_{21}Y_{21} + E_{21}Y_{21} + \ldots\ldots\ldots\ldots E_{2k}Y_{2k} \\ & + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots E_{ik}Y_{ik} \leq \rho j \end{array}$$

and $Y_{ik} \geq 0$ for every i and k

The optimal solution to this problem will be determination of the Y matrix, which in turn defines a k value for each i (i.e., a control option for each emission source). Note that any given k may equal 1, i.e., no control. Controls for any given emission source can be fixed at a predetermined level and the source can thus be removed from the optimization procedure. In general, the program will select those alternatives that reduce emissions the most and cost the least.

After the optimum solution is found, the Y matrix is superimposed onto the E matrices for the other pollutants to determine the emissions of the pollutants that were not restricted. To the optimum totals the program adds the costs and emissions for those sources excluded from the optimization to obtain total industry costs and emissions.

The statement for obtaining minimum emissions for a given cost, T, is very similar:

$$\begin{array}{ll} \text{Minimize} & \Sigma EY \\ \text{subject to:} & \Sigma CY \leq T \\ \text{and} & \Sigma Y = 1 \\ \text{and} & Y \geq 0 \end{array}$$

The approach described above is used in this case also. Operation of the model in either case is identical whether annualized cost or capital cost is the subject of optimization.

The advantage of the model is the ability to rapidly answer "what if" questions. The user can examine sensitivity to variations in the emission factors and control costs by varying the input data.

RESULTS

An example best illustrates the logic of the model. The data base for this example consists of all 216 coke oven batteries, the uncontrolled emission factors presented in Table 1, and the control cost functions as presented in Table 3.

Figure 1 is a graphic presentation of the capital cost functions for the three control options applicable to Source 1, wet coal charging. Every cost function could, of course, be similarly plotted.

Figure 2 shows the annualized cost per pound of particulate removed for the same three options. The spacing of the curves is related to both the relative costs of the options and the relative efficiencies. Although Option 3 is more costly than Option 2, the curves are very close because Option 3 is considerably more efficient than Option 2. Option 4, on the other hand, represents an efficiency improvement of only 0.5 percent over Option 3 at a high cost. Each option for each source and each pollutant could be analyzed in a similar manner.

The function of the model is to analyze all such curves and find the optimum combinations. Figure 3 is the model output to meet a restriction calling for an overall particulate control of at least 95 percent efficiency, which requires the highest possible control level on every source except dry coal charging and the byproducts plant. The latter are excluded because their contributions to particulate emissions are very low; in fact, particulate emissions from the byproducts plant are assumed to be zero in the model. As noted previously, no cost is assigned to the enclosed car option for pushing emissions because the equivalent of an enclosed car is included in the cost of the dry quenching system. Total annualized costs for the industry are $1,396,000,000 and total capital costs (retrofit) are $2,887,000,000. In these examples, the model seeks to minimize annualized costs, not total capital costs. These values do not take into account any existing control, as indicated in the table. Based on similar runs for 80, 85, and 90 percent control, Figure 4 shows the optimum composite cost-effectiveness function for this hypothetical case of no existing controls.

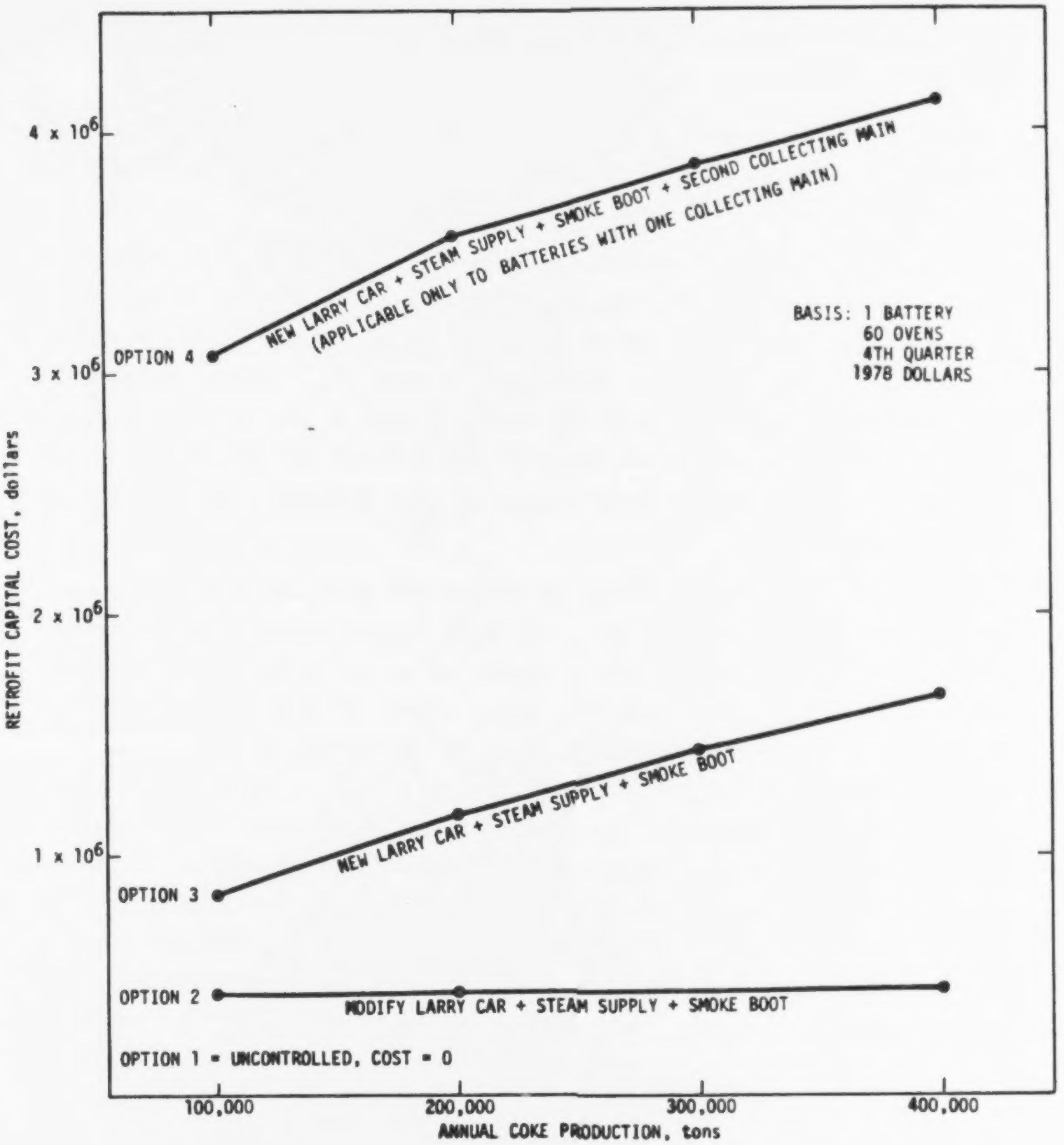

Figure 1. Capital cost of control options for wet coal charging.

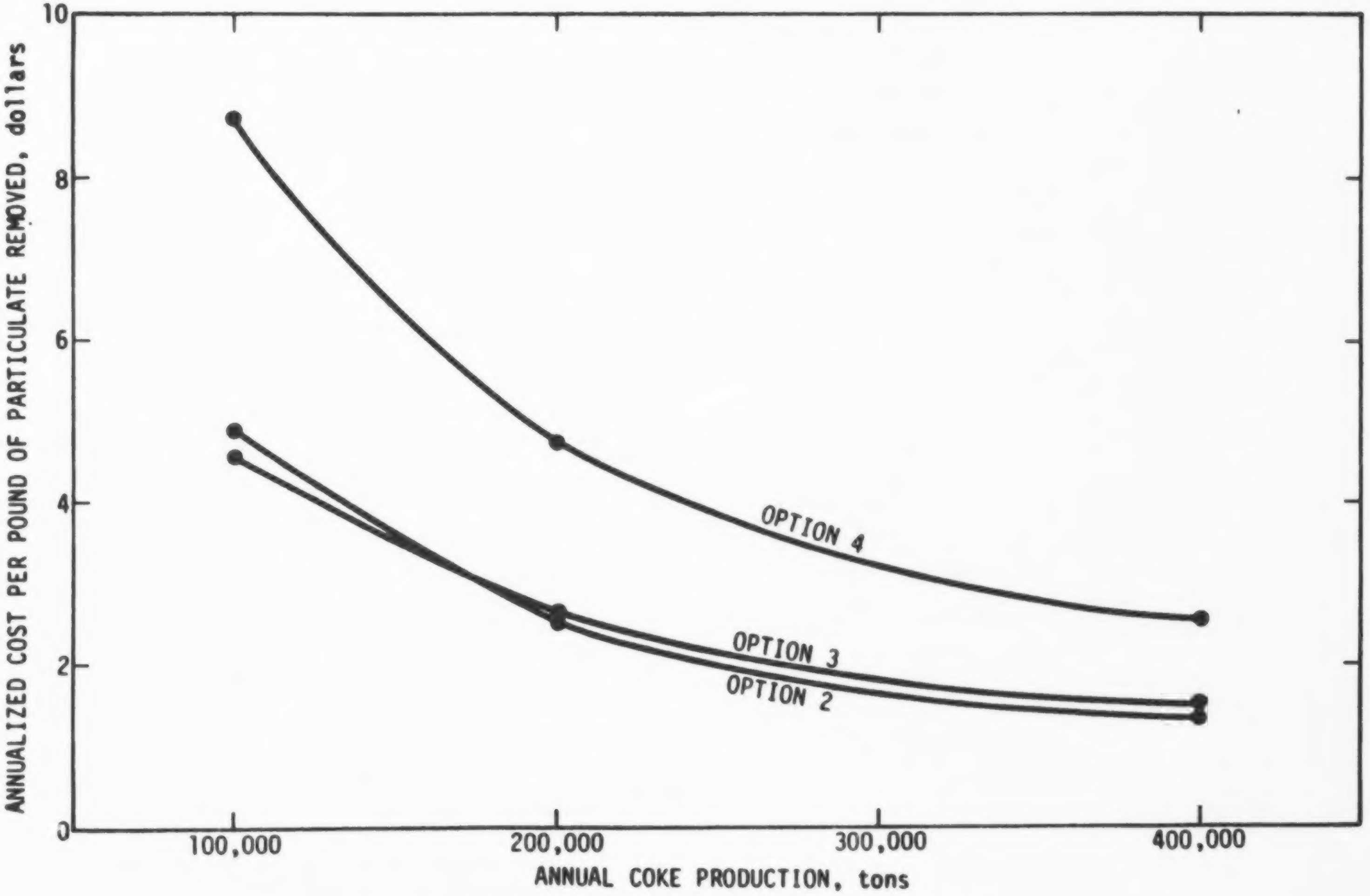

Figure 2. Cost per pound of particulate removed for control options for wet coal charging.

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                    COKE OVEN OPTIMIZATION


           OBJECTIVE: MINIMUM ANNUALIZED COST RESTRICTION:  95.0%  OVERALL EFFICIENCY  POLLUTANT:TSP        BASE YEAR 1979
           BASELINE: ASSUMING NO SIP OR EXISTING CONTROLS


                                             CONTROLLED EMISSIONS                                                  CONTROLLED COST
                                       (LBS/TON COAL)              (TONS/YEAR)                                    (MILLION DOLLARS)

          SOURCE              TSP    BSO    BAP    BEN     TSP    BSO   BAP    BEN   CONTROL SCHEME              CAPITAL  ANNUALIZED
     LARRY CAR CHARGING       .01  .0055  .0000  .0025     240    272     0    124 NEW CAR, SECOND MAIN           649.3      253.6
     COKE PUSHING           # .22  .0440  .0000  .0033   11931   2400     1    180 ENCLOSED HOT CAR                  .0         .0
     QUENCHING - CLEAN WATER  .03  .0000  .0000  .0000     820      0     0      0 DRY QUENCHING                  423.9      111.4
     DOORS                    .03  .0810  .0005  .0056    1464   4433    26    306 DOOR HOOD, SCRUBBER 98%        439.1      481.1
     TOPSIDE                  .01  .0075  .0000  .0002     328    410     1      8 NEW LIDS & CASTINGS             21.8       63.0
     COMBUSTION STACK - OLD   .03  .0030  .0000  .0000     976    112     1      0 BAGHOUSE, 98%                  323.2      111.6
     COKE HANDLING            .11  .0000  .0000  .0000    5965      0     0      0 ENCLOSURES + BAGHOUSE           40.0       16.5
     COAL PREHEATER           .07  .5250  .0002  .0070     359   2675     0     35 ESP 99%                         12.7        5.8
     COAL PREPARATION         .02  .0000  .0000  .0000     820      0     0      0 ENCLOSURE + BAGHOUSE - 99%      29.1       12.7
     COAL STORAGE YARD        .02  .0000  .0000  .0000     820      0     0      0 COAL PILE SPRAYS               147.9       60.6
     PIPELINE CHARGING        .02  .0190  .0000  .0080      49     59     0     24 UNCONTROLLED                     .0         .0
     REDLER CHARGING          .01  .0060  .0000  .0049      13      7     0      6 UNCONTROLLED                     .0         .0
     HOT LARRY CAR CHARGING   .02  .0190  .0000  .0080      10     12     0      5 UNCONTROLLED                     .0         .0
     BY-PRODUCTS PLANT        .00  .3000  .0000  .2000       0  16419     0  10946 UNCONTROLLED                     .0         .0
     COMBUSTION STACK - NEW   .03  .0001  .0000  .0000     446      2     0      0 OVEN PATCHING                    .0       20.1
     QUENCHING - DIRTY WATER  .03  .0001  .0000  .0000     978      1     0      0 DRY QUENCHING                  799.5      251.4


     TOTAL UNC.               9.3  2.235   .006   .686  508238 122349   337  37577
     EXISTING CONTROL                                   388402  76172   254  17656                                297.5      197.1
     EXISTING EFFICIENCY                                  23.6   37.7  24.6   53.0
     BASELINE CONTROL                                   508237 122348   337  37577                                   .0         .0
     BASELINE EFFICIENCY                                    .0     .0    .0     .0
     TOTAL CONTROLLED                                    25238  26816    32  11638                              . 2086.6     1395.8
     PERCENT CONTROLLED                                   95.0   78.1  90.5   69.0

               EXISTING                                              NEW
          TOTAL BATTERIES 216    TOTAL OVENS 12221         TOTAL BATTERIES   0    TOTAL OVENS    0

          TOTAL CAPACITY  109494267  TONS COAL             TOTAL CAPACITY         0  TONS COAL

                           76623000  TONS COKE                                    0  TONS COKE

          # NOT IN OPTIMIZATION
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Figure 3. Model output for 95 percent overall particulate reduction.

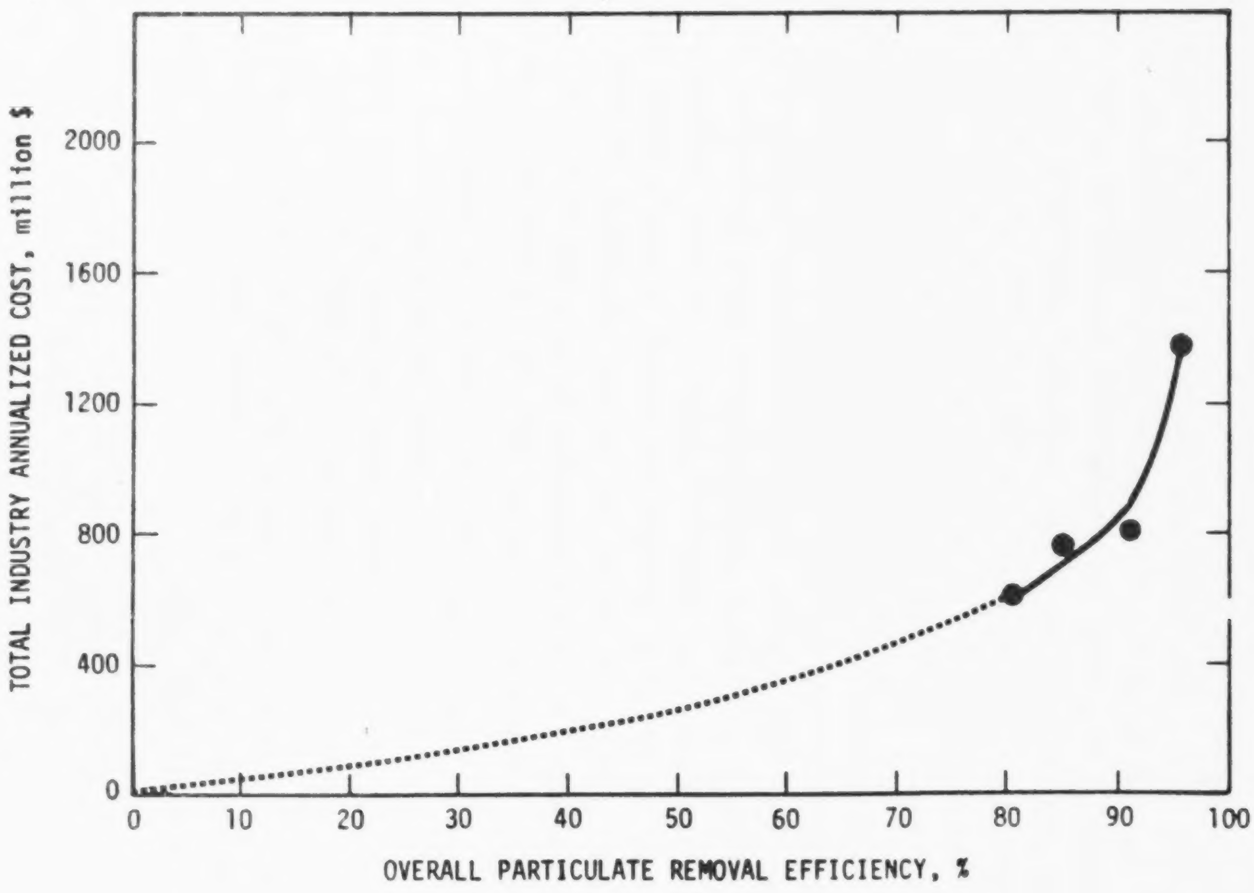

Figure 4. Total annualized cost as a function of overall efficiency.

Cost is presently overstated in some cases because each battery is treated independently. An example would be a plant with four batteries, at which both door hoods and a wastewater recirculation system are provided for each battery. In such a scheme it is likely that one common water system could be installed to serve all four batteries for less than the cost of four separate water systems. Similarly, if a shed and scrubber were installed to control pushing emissions and coke-side door emissions, and a hood system were installed for push-side doors, the water system (and perhaps the scrubber itself) could be designed to handle both sources. The existing model can be modified to address these issues, but specific assumptions will be required.

When a different pollutant is examined, quite different results are seen. Figure 5 illustrates an example of minimizing BaP emissions for an annualized cost restriction of $575,000,000. The resultant control efficiency for BaP is 89 percent, although particulate control drops to about 50 percent. In this example, existing control was taken into account. As seen in Figure 4, the annualized cost for 89 percent particulate control is nearly double that for equivalent BaP control, and capital cost is proportionately even more. Capital cost is a somewhat misleading parameter because many of the control options do not use capital equipment but rather operating and maintenance programs.

These examples clearly represent only a few of the cases that can be evaluated. The results for other pollutants and emission factors, different control functions, and battery subsets have not been examined. These are among the many possibilities that remain for the users of the model.

Consideration is now being given to expanding the model concept to include wastewater, solid waste, and energy impact, and to expanding the scope to include other processes.

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                     COKE OVEN OPTIMIZATION

        OBJECTIVE: MINIMUM EMISSIONS   RESTRICTION: $ 575. MILLION ANNUALIZED COST     POLLUTANT:BAP         BASE YEAR 1979
        BASELINE: COST ADJUSTED FOR EXISTING CONTROLS


                                          CONTROLLED EMISSIONS                                                          CONTROLLED COST
                                   (LBS/TON COAL)               (TONS/YEAR)                                             (MILLION DOLLARS)

          SOURCE               TSP     BSO     BAP     BEN     TSP     BSO     BAP     BEN    CONTROL SCHEME              CAPITAL  ANNUALIZED
    LARRY CAR CHARGING         .01   .0110   .0000   .0050     496     545       0     248 NEW CAR, STEAM, BOOT           303.6      164.7
    COKE PUSHING              2.00   .0800   .0000   .0060  109463    4378       2     328 UNCONTROLLED                      .0         .0
    QUENCHING - CLEAN WATER    .17   .0002   .0000   .0000    4104       4       0       0 DIVERTED FLOW BAFFLES            5.8       14.0
    DOORS                      .08   .1000   .0006   .0040    4378    5473      32     218 CLEAN AFTER EVERY CHARGE        84.2      182.4
    TOPSIDE                    .01   .0075   .0000   .0002     328     410       1       8 NEW LIDS & CASTINGS            21.8       63.0
    COMBUSTION STACK - OLD     .26   .0012   .0000   .0000    9768      45       0       0 OVEN PATCHING                    .0       88.6
    COKE HANDLING             1.00   .0000   .0000   .0000   54731       0       0       0 UNCONTROLLED                     .0         .0
    COAL PREHEATER             .35   .4200   .0002   .0070    1796    2140       0      35 SCRUBBER, 95%                   2.5        2.1
    COAL PREPARATION           .50   .0000   .0000   .0000   27365       0       0       0 UNCONTROLLED                     .0         .0
    COAL STORAGE YARD          .15   .0000   .0000   .0000    8209       0       0       0 UNCONTROLLED                     .0         .0
    PIPELINE CHARGING          .00   .0002   .0000   .0001       0       0       0       0 OPERATION & MAINT.               .0        3.2
    REDLER CHARGING            .00   .0001   .0000   .0000       0       0       0       0 OPERATION & MAINT.               .0         .7
    HOT LARRY CAR CHARGING     .00   .0002   .0000   .0001       0       0       0       0 OPERATION & MAINT.               .0         .3
    BY-PRODUCTS PLANT          .00   .3000   .0000   .2000       0   16419       0   10946 UNCONTROLLED                     .0         .0
    COMBUSTION STACK - NEW     .03   .0001   .0000   .0000     446       2       0       0 OVEN PATCHING                    .0       20.1
    QUENCHING - DIRTY WATER    .96   .0019   .0001   .0003   29361      58       2       7 BAFFLES                         9.3        3.5


        TOTAL UNC.          18.7  3.339    .007    .766 508238 122349    337  37577
        TOTAL CONTROLLED     5.5   .922    .001    .223 250445  29474     37  11790                                      429.3      542.5


              EXISTING                                                 NEW
        TOTAL BATTERIES 216    TOTAL OVENS 12221          TOTAL BATTERIES   0    TOTAL OVENS     0

        TOTAL CAPACITY  109494267  TONS COAL              TOTAL CAPACITY          0  TONS COAL

                         76623000  TONS COKE                                      0  TONS COKE

        # NOT IN OPTIMIZATION
```

Figure 5. Example of minimizing BaP emissions for an annualized cost restriction.

VOLATILIZED LUBRICANT EMISSIONS FROM STEEL ROLLING OPERATIONS

Written By

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Presented at

Symposium on Iron and Steel
Pollution Abatement Technology

October 30 - November 1, 1979

Pick-Congress Hotel
Chicago, Illinois

VOLATILIZED LUBRICANT EMISSIONS FROM STEEL ROLLING OPERATIONS

The paper presents the findings of two reports prepared by Pacific Environmental Services, Inc. (PES) for the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency (IERL, EPA). The first report entitled "The Use and Fate of Lubricants, Oils, Greases, and Hydraulic Fluids in the Iron and Steel Industry", was the first study of lubricant usage within the steel industry and its overall environmental impact. The report was concentrated in two areas: (1) the development of correlations between lubricant usage rates and the steel production capacity and the types of products made; and (2) the preparation of total oil, grease, and hydraulic fluid material balances for specific as well as typical integrated steel plant.

Lubricant-type materials in the steel industry can generally be broken down as greases, lubricating oils, process oils, and hydraulic fluids. Due to the variety of operation and the amount and size of the equipment used, no other industry employs a more complete range of lubricants. High and low temperatures, shock loading, exposure to water, and abrasive materials are some of the adverse conditions normally encountered. All types of motors, turbines, bearings, gears, and drives must be properly lubricated to keep the machinery functioning. A typical steel mill may have over 400,000 lubrication points using as many as 150 different specifications for lubricants.

Grease is generally used under the following conditions: (1) where there is no way to retain oil for the part being lubricated; (2) when the lubricant must act as a seal to prevent the entrance of dirt; (3) when a lubricant is seldom added; and (4) where speeds are low and pressures are high. Oils are used for a wide variety of purposes. Very simply, oils are used in all cases where operating conditions do not dictate the use of grease. A basic list of common oils include:

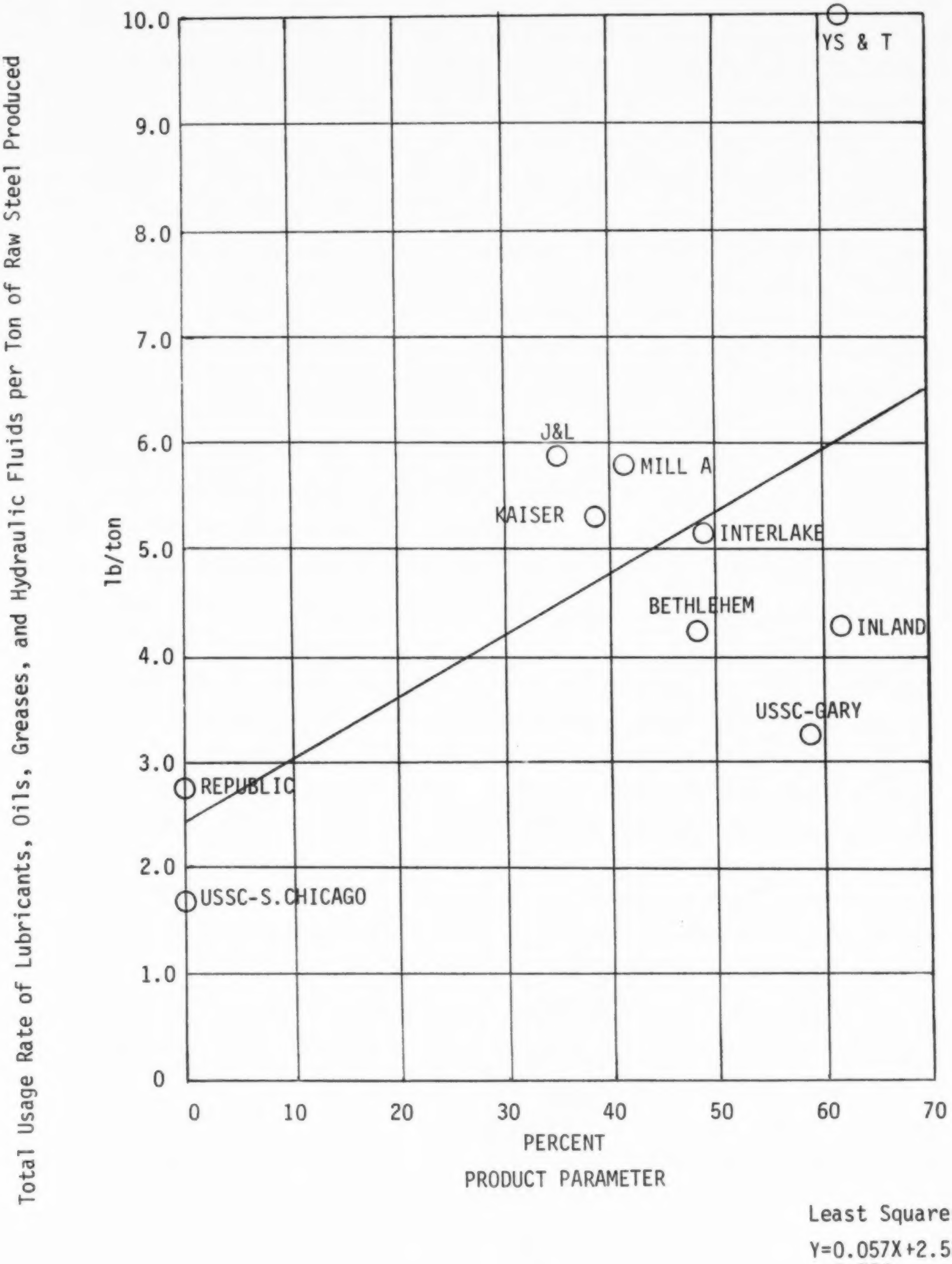
engine oils, extreme pressure oils, rust and oxidation inhibiting (R & O) oils, rolling oils, and protective coating oils. Hydraulic fluids are generally oil-based products and come in slightly less variety than lubricating oils and greases. Some typical products in use include: invert emulsions, phosphate ester fluids, water-glycol fluids, rust and oxidation inhibiting hydraulic oil, and extra-duty anti-wear hydraulic oil.

The prime objective of the initial PES study was to analyze data obtained from the steel industry, and to use this information to develop material balance estimates identifying the usage and fate of lubricants, oils, greases, and hydraulic fluids. The major factors which influence lubricant usage (and their fate) are the size, design, and age of the steel mill equipment. Generally speaking, mill equipment which is large and old requires substantially more lubricants than would a smaller or newer piece of equipment. The lubrication practices and application methods also vary widely from mill to mill. The last major factor (the type of steel product produced) determines the amount of lubricant used within an entire mill since the majority of lubricant used (between 80 and 90 percent) in an integrated mill, is used in hot and cold rolling processes.

These factors, as well as maintenance and housekeeping practices, influence the amounts and types of lubricants applied, and to some extent, the fate of these lubricants. Figure 1 depicts this relationship by using a product parameter developed by PES. To obtain a relative percentage of rolled strip and coiled products, the sum of all hot strip, cold rolling, cold finishing and temper mill capacities at each plant was divided by the sum of all shaping, rolling, and finishing mill capacities. This parameter is expressed as a percentage. Plants with large capacities to roll hot strip or cold rolled products have product parameters of around 60 percent.

To develop a material balance over an integrated mill, in addition to lubricant usage terms, output or loss terms must be identified and

Figure 1. TOTAL USAGE RATE VS. PRODUCT PARAMETER



Least Squares Line

Y=0.057X+2.53
r=0.580
N=10
p=90 to 95%

quantified. Figure 2 illustrates both sides of a lubricant mass balance over an entire mill. Two input terms, virgin make-up, and reclaimed or recycled lubricants, and hydraulic fluids enter the material balance. Several output or loss terms are identified in the figure, including: lubricant losses on the steel products shipped from plant; oils and greases attached to mill scales which are stockpiled or recycled to the sinter plant; lubricants, especially greases, left in containers or lost during storage and handling; oils and greases on trash and debris that are collected and disposed; lubricants volatilized, burned, or consumed in various steel making and shaping processes; and oils, greases, and hydraulic fluids in the wastewater streams which are either discharged to waterways, recovered and disposed, or are reclaimed. Oils, greases, and hydraulic fluids are also collected by oil skimmers, in scale pits and wastewater treatment facilities, and are treated on- or off-site in waste oil reclamation facilities for re-use as lubricants, fuels, or road oils.

Quantifying each of these input and loss terms for each oil, grease, or hydraulic fluid was determined to be an impossible task. A given lubricant may be used in several areas or pieces of equipment and may appear in several wastewater circuits. The wastewaters from different areas of the plant are often combined, resulting in a blend of oils, and greases which cannot be separated and traced back to their source. The wastewater sampling and analysis methods that are currently being used only determine the total quantity of oil, grease, and hydraulic fluids. Several of the output or loss terms, although recognized by the steel industry, have not been investigated to date and quantitative data of any type is unavailable.

PES obtained sufficient lubrication data to develop balance scenarios for several mills. Summaries are presented in Tables 1 and 2. As seen in Table 1, overall lubricant usage ranged from a low of 1.63 pounds of lubricant/ton of product, to a high of 9.99 lb/ton with the average being 4.81 lb/ton. Also, note that the two mills with

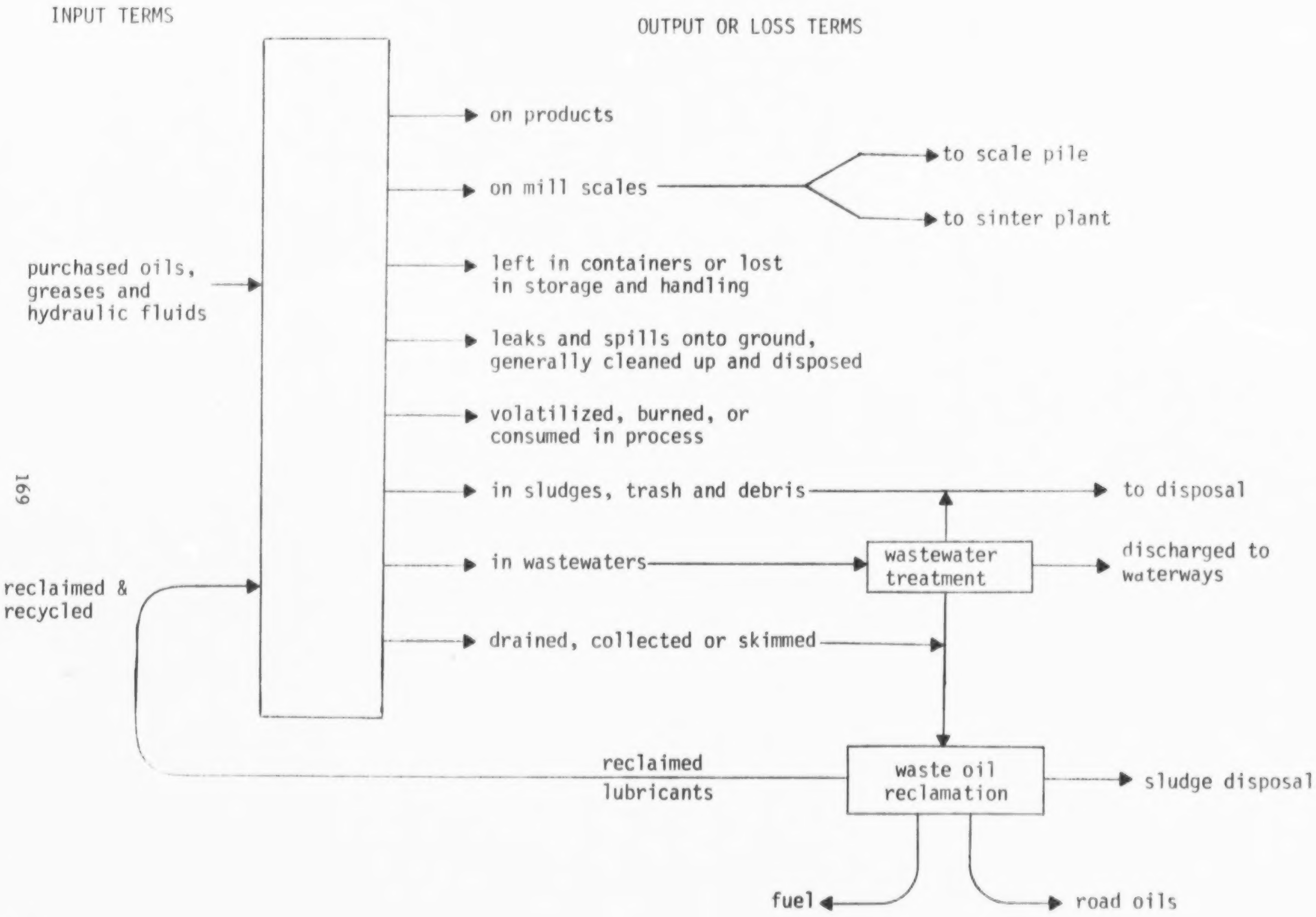

INPUT TERMS
OUTPUT OR LOSS TERMS
purchased oils, greases and hydraulic fluids
reclaimed & recycled
on products
on mill scales
to scale pile
to sinter plant
left in containers or lost in storage and handling
leaks and spills onto ground, generally cleaned up and disposed
volatilized, burned, or consumed in process
in sludges, trash and debris
to disposal
in wastewaters
wastewater treatment
discharged to waterways
drained, collected or skimmed
reclaimed lubricants
waste oil reclamation
sludge disposal
fuel
road oils

Figure 2. LUBRICANT, OIL, GREASE, AND HYDRAULIC FLUID MATERIAL BALANCE ESTIMATE

Table 1. USAGE AND PRODUCT DATA

STEEL MILL	PRODUCT PARAMETER*	TOTAL OIL, GREASE & HYDRAULIC FLUID USAGE		TOTAL OIL USAGE	
USSC, Gary	59	1.653	(3.306)	1,473	(0.353)
USSC, South Chicago	0	0.816	(1.632)	0.146	(0.035)
Inland Steel	62	2.120	(4.240)	2.069	(0.496)
Youngstown Sheet & Tube	61	4.997	(9.993)	3.671	(0.880)
Bethlehem Steel	49	2.126	(4.252)	1.381	(0.331)
Jones & Laughlin	35	2.981	(5.961)	1.677	(0.402)
Republic Steel	0	1.377	(2.754)	0.780	(0.187)
Interlake	49	2.566	(5.131)	2.674	(0.641)
Kaiser Steel	39	2.642	(5.284)	2.311	(0.554)
Mill A	42	2.815	(5.630)	2.920	(0.700)
Units	%	kg/1000 kg	(lb/ton)	l/1000 kg	(gal/ton)

* The sum of all hot strip, cold rolling, cold finishing, and temper mill capacities at each plant divided by the sum of all shaping, rolling, and finishing mill capacities.

Table 2. SUMMARY OF MATERIAL BALANCE LOSS TERMS

LOSS TERMS	USCC GARY	INLAND	YS & T	BETH.	J & L	REP.	KAIS.	MILL A	AVG.	RANGE	"TYPICAL MILL"
On Products	3.6	3.4	1.5	4.7	19.4	5.0	0.9	7.6	5.8	0.9 - 19.4	6
On Mill Scales	1.1	13.7	3.6	2.3	20.1	9.3	34.3	6.9	11.4	1.1 - 34.3	11
Discharged to Waterways	7.1	3.7	11.7	14.1	9.8	7.0	0.1	10.7	8.0	0.1 - 14.1	8
In Sludge, Trash & Debris	28.5	21.8	46.8	55.6	52.8	54.7	35.0	14.5	38.7	14.5 - 55.6	39
To Reclaimers	53.8	14.1	12.1	14.5	0	0	8.5	46.9	18.7	0.0 - 53.8	19
Left in Containers	0.9	?	?	5.0	?	?	5.0	0.3	2.8	0.3 - 5.0	3
Leaks & Spills	0.7	0.4+ ?	0.2+ ?	3.7	?	?	5.0	1.3	1.9	0.2 - 5.0	2
Volatilized or Consumed	3.7	?	?	2.0	?	?	12.6	9.7	7.0	2.0 - 12.6	7
TOTAL	99.4	57.1	75.9	101.9	102.1	76.0	101.4	97.9			95
UNACCOUNTED FOR	0.6	42.9	24.1	-	-	24.0	-	2.1			5

Notes: 1. All numbers represent percentage of total lubricant, oil, grease, and hydraulic fluid input to the steel mill.

2. Whole number values were selected for the "typical mill", reflecting the accuracy of available data and estimates.

product parameters of zero (No rolling mills) have the two lowest lubricant usage figures. Table 2 summarizes the Material Balance Loss Terms of the mills surveyed. Note that many of the mills did not have data for potentially large loss term factors such as the quantities volatilized or consumed.

The loss term percentages for a typical steel mill shown in the last column of Table 2 were applied to the total oil, grease, and hydraulic fluid usage rate estimated for a 4.0 x 10^6 ton/year capacity plant. This usage rate was estimated to be about 1,200,000 lb/month. Multiplying this usage rate by the loss term percentages, a material balance estimate was derived for a typical mill. Table 3 summarized the potential pollution which could be generated by a typical 4.0 x 10^6 ton/year integrated mill. This estimate revealed that of the total quantity of oil, grease, and hydraulic fluid used at a typical plant, approximately 10 percent enters the environment as air pollution, 9 percent as water pollution, and 44 percent as solid waste.

Since the first study showed that the majority of lubricant used in the steel industry is used in steel rolling operations, a new study was funded to refine the lubrication data and the above emission estimates at these locations. As in the first study, data from nine steel rolling operations were used to: (1) define the volatilized portion of lubricants used in rolling operations; and (2) prepare total oil, grease, and hydraulic fluid material balances for actual and typical cold and hot rolling processes from data acquired by questionnaires, mill visits, and emission source sampling. The major difference between the first and second study was the addition of actual source sampling. The remainder of this paper will focus on that aspect. Sampling was conducted at three rolling operations, two at Inland Steel Indiana Harbor Works, and one at United States Steel Gary Works.

Table 3. POLLUTION SUMMARY

LOSS TERM	PERCENT	AIR POLLUTION	WATER POLLUTION	SOLID WASTE	ASSUMPTIONS
On Products	6	-	-	-	No resulting pollution.
On Mill Scales	11 6	-	1	1	Of the 6% of oil in stockpiled mill scale 1% is washed off and becomes water pollution; 1% is permanently "stored".
	5	4	-	-	Of the 5% of oil in recycled mill scale 4% is volatilized and the remainder is combusted or captured
Discharged to Waterways	8	-	8	-	
In Sludge, Trash & Debris	39	-	-	39	The fate of oil in landfills was not considered
To Reclaimers	19	-	-	1	One percent sludge from the reclamation process. The potential air pollution from fuel combustion was not considered.
Left in Containers	3	-	-	1	One percent is in containers which are discarded in a landfill.
Leaks & Spills	2	-	-	2	All leaks and spills are cleaned up and disposed of in landfills.
Volatilized or Consumed	7	6	-	-	One percent is combusted.
TOTAL	95	10	9	44	32% does not result in air or water pollution or solid waste and 5% is unaccounted for.

The two mills sampled at Inland Steel were the 56 inch four-stand tandem cold strip mill, and the 80 inch five-stand tandem cold strip mill. Both of these mills had a central air evacuation system which exhausted to a central stack (one stack for each mill). The evacuation system is necessary since large amounts of water and oil would condense on the rolling train if they were not removed. Also, cold mill operators must work very near the rolling train, and the evacuation system prevents oil and water from hindering the operator's ability to perform their assignments. Mist eliminators are located in underground exhaust tunnels which aid in the elimination of any aerosols which may reach the evacuation systems induction (I.D.) fans. The collection efficiency of the evacuation system was estimated by PES to be 95 percent with the remaining five percent escaping to the mill building atmosphere.

The sampling train used to sample the hydrocarbons in the exhaust stack was basically a method five train with a Beckman 400 hydrocarbon analyzer placed in series with the train. Continuous HC stack sampling was conducted and measured on the HC analyzer for approximately 90 minutes in each of the cold mills. The actual average total hydrocarbon concentrations for 56 inch and 80 inch mills were determined to be 60 and 57 ppm (as methane) respectively.

Grab samples were taken from each of the mills' stacks during the period when continuous stack hydrocarbon sampling was being conducted. The chemical analysis of these samples revealed that the majority of hydrocarbons were aliphatic in nature. The aliphatic hydrocarbons were further identified to be in the C-14 through C-38 range. The majority of the aliphatic hydrocarbons emitted through the 56 inch mill stack were in the C-16 to C-18 range while those of the 80 inch mill were concentrated in the C-14 to C-28 range. These ranges correspond to the chain lengths of the rolling solution prior to rolling so it appears th ; little chemical decomposition occurs during the rolling process.

The relative hydrocarbon emissions concentrations appear to be quite low. However, when you incorporate the large air volumes and the approximate operating schedules of the 56 inch and 80 inch cold strip mills, the total yearly volatilized hydrocarbon emission rate becomes 60 and 64 ton/year respectively. For the 56 inch cold strip mill 60 ton/year of volatilized hydrocarbons reduces to 20.8 percent of all lubricants used on the mill exclusive of hydraulic oil. The 64 ton/year emission rate for the 80 inch cold strip is 26.9 percent of the total mill lubricant usage exclusive of hydraulic oil. In both cases, the volatilization term is the second largest term in the cold strip mill lubrication mass balance, with waste oil drained and collected being the single largest term (approximately 45 percent for both mills).

The testing conducted at United States Steels' 84 inch hot strip mill at the Gary Works facility was not as straight forward as the tests used on the cold strip mills. This hot strip mill has the capability to use rolling oil at the finishing stands. Unfortunately, no rolling oil was used during the hot reduction operation due to winter damage to the mills' coolant/lubricant application system.

A portable organic vapor analyzer (Century Systems Model OVA-108) was used for the hydrocarbon emission monitoring. The exhaust from the hot roll operations area vents directly to the ambient (building) atmosphere. The hot mill complex is not equipped with any central air evacuation system, and no control stack duct exists through which the hot mill and exhaust air can be discharged into the outer atmosphere. All vapors generated by the process eventually exit through roof monitors located directly over each of the mill stands. Since there was no central location to measure the generated vapors, readings were taken at the top of each of the mills' finishing stands. The hydrocarbon concentrations ranged between 7 ppm and 23 ppm as methane, with the average ppm being 15.

In an effort to quantify the total volatilization emissions from this mill the following approach was taken. The rate of evaporation of oil and water in the surface film on the strip depends on the following principle factors:

1. Surface area of strip.
2. Speed of the strip.
3. Temperature of the steel strip.
4. Thickness of the surface film.
5. Specific heat of the steel strip and rolling oil film.
6. Ambient air temperature.

PES engineers assumed the exit rate of the volatilized vapors was approximately equal to the speed of the strip at each stand. This assumption was made because the following conditions exist:

1. No central duct - since this is the case, a stack duct which was the width of the strip and the length of the finishing stand was imagined.

2. Dilution air would tend to dilute the concentration. However, this has a net negative effect on overall emissions.

3. Hydrocarbons which escape the imagined duct could not be accounted for. Again, this has a net negative effect on overall emissions.

The actual speed of the hydrocarbon vapors is probably somewhat less than the actual speed of the strip which would yield a net positive effect on overall hydrocarbon emissions. However, since the dilution air and the vapor escape factors tend to reduce the hydrocarbon emissions at the point of sampling, the assumption of an escape velocity equal to the speed of the strip at a concentration of 15 ppm at the height of the strip was deemed acceptable. By using this assumption, an annual hydrocarbon emission rate of 42 ton/year was obtained for the 84 inch hot strip mill.

As a last exercise, emission factors for typical cold and hot strip mills were developed. It should be stated that the designation of a typical mill is somewhat loose since mill designs and operating practices vary greatly. The cold mill emission factors were estimated to be accurate within a range of ± 20 percent.

In the case of hot strip mills, the amount of data was significantly less than that available for cold strip mills. Therefore, the emission factors may vary as much as an order of magnitude.

It was determined that for a typical cold strip mill approximately 0.34 lb/ton of hydrocarbons (as methane) will be emitted under normal operation. The emission factor for a hot strip mill which does not utilize rolling oils was determined to be 0.019 lb/ton of product. These factors were expanded to show that for an average rolling operation (either hot or cold), approximately 3.7 percent of the lubricant purchased for that operation is volatilized. The above calculation assumes only one rolling operation is required to obtain a final product. If one assumes each final product undergoes three rolling operations, then the total amount of lubricant volatilized is approximately 11 percent of the lubricants purchased for rolling operations.

EMISSION FACTORS FOR OPEN DUST SOURCES

By

Chatten Cowherd, Jr.*

ABSTRACT

The information presented in this paper is directed to those interested in inventorying particulate emissions from open dust sources within integrated iron and steel plants. The results of a recent field testing program are used to refine previously developed emission factor equations for generic source operations including vehicular traffic on unpaved and paved surfaces, batch drop operations, continuous drop operations, and wind erosion. Significant improvements in emission factor precision are achieved through the following modifications: (a) addition of a wheel number correction term to the equation for unpaved roads; (b) addition of road shoulder and lane number correction terms to the equation for paved roads; and (c) addition of a drop distance correction term to the equation for continuous drop operations. Wind erosion test results indicate that natural surface crusts are very effective in mitigating dust emissions, an effect which is not taken into account in the previously developed emission factor equation. Limited testing of chemical dust suppressants applied to unpaved roads indicates a high initial control efficiency (exceeding 90%) which decreases by more than 10% with the passage of 200 to 300 vehicles. Consistent with the emission factor equation, the lowering of emissions is reflected by the reduced silt (fines) content of the road surface material after the application of chemical dust suppressants.

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INTRODUCTION

Iron- and steel-making processes, which are characteristically batch or semicontinuous operations, generate substantial quantities of fugitive (nonducted) emissions at numerous points in the process cycle. There are numerous materials handling steps in the storage and preparation of raw materials and in the disposal of process wastes. Additionally, fugitive emissions escape from reactor vessels during charging, process heating, and tapping.

Fugitive emissions in the iron and steel industry can be generally divided into two classes--process fugitive emissions and open dust source fugitive emissions. Process fugitive emissions include uncaptured particulates and gases that are generated by steel-making furnaces, sinter machines, and metal forming and finishing equipment, and that are discharged to the atmosphere through building ventilation systems. Open dust sources of fugitive emissions include such sources as raw material storage piles, from which emissions are generated by the forces of wind and machinery acting on exposed aggregate materials.

Fugitive emissions are especially difficult to characterize for the following reasons.

1. Emission rates have a high degree of temporal variability.

2. Emissions are discharged from a wide variety of source configurations.

3. Emissions are comprised of a wide range of particle sizes, including coarse particles which deposit immediately adjacent to the source.

The scheme for quantification of emission factors must effectively deal with these complications.

In a recent study of fugitive emissions from integrated iron and steel plants, Midwest Research Institute determined that open dust sources (specifically, vehicular traffic on unpaved and paved roads and storage pile activities) ranked with steel-making furnaces and sinter machines as sources which emit the largest quantities of fine and suspended particulate, taking into account typically applied control measures. 1/ It became evident that open dust sources should occupy a prime position in control strategy development for fugitive particulate emissions within integrated iron and steel plants. Moreover, preliminary analysis of promising control options for both process sources of fugitive emissions and open dust sources indicated that control of open dust sources has a highly favorable cost-effectiveness ratio for particulate.

The technical soundness of these conclusions and the foundation for more detailed investigation rest on the availability of reliable particulate emission factors and particle size distributions for the sources under consideration. This paper presents refined emission factors for open dust sources developed from an expanded data base incorporating the results of additional field testing within integraded iron and steel plants.

Previously Developed Emission Factors

Since 1973, MRI has been engaged in a series of field testing programs to develop emission factors for open dust sources associated with agriculture and industry. To provide for the requirement that the emission factors would be applicable on a national basis, at the outset MRI analyzed the physical principles of fugitive dust generation to ascertain the parameters which would cause emissions to vary from one location to another. These parameters were found to be grouped into three categories:

1. Measures of source activity or energy expended (for example, the speed and weight of a vehicle traveling on an unpaved road).

2. Properties of the material being disturbed (for example, the content of silt in the surface material on an unpaved road).

3. Climatic parameters (for example, number of precipitation-free days per year on which emissions tend to be at a maximum).

By constructing the emission factors as mathematical equations with multiplicative correction terms, the factors developed by MRI became applicable to a range of source conditions limited only by the extent of experimental verification.[2,3]

The use of the silt content as a measure of the dust generation potential of a material acted on by the forces of wind or machinery was an important step in extending the applicability of the emission factor equations to the wide variety of aggregate materials of industrial importance. The upper size limit of silt particles (75 μm in diameter) is the smallest particle size for which size analysis by dry sieving is practical, and this particle size is also a reasonable upper limit for particulates which can become airborne. Analyses of atmospheric samples of fugitive dust indicate a consistency in size distribution so that particles in specific size ranges exhibit fairly constant mass ratios.[2,3]

In order to quantify source-specific emission factors for open dust sources, MRI developed the "exposure profiling" technique, which uses the isokinetic profiling concept that is the basis for conventional source testing.[4] Exposure profiling consists of the direct measurement of the passage of airborne pollutant immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model.

The emission factors developed by MRI have been made specific to particles smaller than 30 μm in Stokes diameter, so that emissions may be related to ambient concentrations of total suspended particulate. The upper size limit of 30 μm for suspended particulate is the approximate effective cutoff diameter for capture of fugitive dust by a standard high volume particulate sampler (based on a typical particle density of 2 to 2.5 g/cm).[2] It should be noted, however, that analysis of parameters affecting the atmospheric transport of fugitive dust indicates that only the portion smaller than about 5 μm in diameter will be transported over distances greater than 5 to 10 km from the source.[5]

Test Results from Steel Plants

In 1977, as noted above, MRI performed field testing of open dust sources at two integrated iron and steel plants (designated as Plants A and E) in order to extend the applicability of the previously developed emissions factor equations to open dust sources in the iron and steel industry.[1] The sources tested were: (a) light-duty vehicular traffic on unpaved roads; (b) heavy-duty vehicular traffic on unpaved roads; (c) mixed vehicular traffic on paved roads; (d) mobile stacking of lump iron ore; (e) mobile stacking of pelletized iron ore; and (f) load-out of processed slag into a truck with a front-end loader. These sources involved materials handling equipment of a scale significantly larger than had been tested previously. However, as indicated in Table 1, the expanded data base incorporating the results of these tests still was not adequate to provide emission factor equations with a high degree of quality assurance.

Therefore in 1978 a follow-up field testing program was conducted at three integrated iron and steel plants (designated as Plants F, G, and H). The following tests were performed:

- Six tests of medium-duty vehicular traffic on untreated, unpaved roads.

TABLE 1. EMISSION FACTOR QUALITY ASSURANCE LIMITATIONS
(Effective March 1978)

Source	Typical percent of total controlled TSP emissions[6]	Emission factor QA rating[a]	Test data limitations[b]
. Vehicular traffic on unpaved surfaces	65		
Unpaved roads		B - dry conditions C - annual conditions	I I; questionable measurement accuracy
Storage pile maintenance		C	I; testing under dry conditions only
. Vehicular traffic on paved surfaces	15	B - urban traffic C - industrial traffic	I I; probable effect of dust resuspension from underbodies
. Batch drop operations (loaders, railcars, trucks, gantry/clamshell buckets)	1	B - loaders C - other	I
. Continuous drop operations (stackers, conveyor transfer stations, bucket wheels)	5	B - stackers C - other	I
. Wind erosion	14		
Storage piles		C	I; questionable measurement accuracy
Exposed areas		C	I; testing limited to dry uncrusted surfaces

[a] Quality assurance rating scheme:
A = formulation based on statistically representative number of accurate field measurements (emissions, meteorology and process data) spanning expected parameter ranges
B = formulation based on limited number of accurate field measurements
C = formulation or specific value based on limited number of measurements of undetermined accuracy or extrapolation of B-rated data from similar processes
D = estimate made by knowledgeable personnel
E = assumed value

[b] I = insufficient number of tests

- Three tests of light-duty vehicular traffic on untreated, unpaved roads.

- Two tests of light-duty vehicular traffic on treated unpaved roads.

- Six tests of mixed vehicular traffic on paved roads.

- Five tests of storage pile stacking of pelletized iron ore and coal.

- Eight tests of wind erosion from coal storage piles.

- Four tests of wind erosion from bare ground areas.

This mix of tests was derived from statistical analysis of source contributions and the relative reliabilities of previously developed emission factor equations. To the extent possible, testing was restricted to periods with moderate winds (5 to 15 mph) of constant mean direction, 3 or more days after significant rainfall (accumulation exceeding 0.5 in.).

The primary tool for measuring fugitive dust generated from open dust sources was the MRI Exposure Profiler. A vertical line grid of samplers was used for measurement of dust emissions from vehicular traffic on unpaved and paved roads. For the remaining sources, a cross-arm supporting additional samplers was added so that both the vertical and lateral dimension of the dust plume could be defined. At all times the MRI Exposure Profiler was positioned within 5 m of the source with air samplers covering the effective cross section of the fugitive dust plume.

Other equipment utilized in the testing included (a) cascade impactors with cyclone preseparators for particle sizing, (b) high-volume air samplers for determining upwind particulate concentrations, and (c) recording wind instruments utilized to determine mean wind speed and direction for adjusting the MRI Exposure Profiler to isokinetic sampling conditions. A detailed presentation of the testing methodology is provided elsewhere.[6]

In order to determine the properties of aggregate materials being disturbed by the action of machinery or wind, representative samples of the materials were obtained for analysis in the laboratory. Unpaved and paved roads were sampled by removing loose material (by means of vacuuming and/or broom sweeping) from lateral strips of road surface extending across the traveled portion. Storage piles were sampled to a depth exceeding the size of the largest aggregate pieces.

Moisture contents of samples were determined in the laboratory by weight loss after oven drying at 110°C, and texture was determined by standard dry sieving techniques. The moisture content of an exposed aggregate material is dependent on its initial moisture content and on the precipitation and evaporation which occurs while the material is in place. Thornthwaite's P-E Index[4] is a useful approximate measure of average surface soil moisture, but is not suitable for freely draining aggregate stored in open piles.

REFINEMENT OF EMISSION FACTOR EQUATIONS

This section presents refined emission factor equations for: (a) vehicular traffic on unpaved roads; (b) vehicular traffic on paved roads; (c) storage pile formation by continuous load-in or stacking; and (d) wind erosion of storage piles and bare ground areas. Refinements to previously developed equations have been adopted as necessary to extend the predictive capability of the equations to the expanded test data bases without loss in precision. In this way, the quality assurance (QA) ratings, as given in Figure 1, may be improved.

Vehicular Traffic on Unpaved Roads

Figure 1 shows the predictive emission factor equation for vehicular traffic on unpaved roads, as derived by multiple regression analysis of the test data shown in Table 2. The coefficient and the first two correction terms in Figure 1 are identical to the expression given in AP-42 as follows:[7]

$$0.6\ (0.81\ s)\left(\frac{S}{30}\right)$$

which describes the emissions of particles smaller than 30 μm in Stokes diameter generated by light duty vehicles traveling on unpaved roads. The weight correction term in Figure 1 was developed on the basis of prior testing; however, the term was formerly raised to the 0.8 power.[1]

Table 2 compares measured emissions with predicted emissions as calculated from the equation given in Figure 1. In addition to the test results from iron and steel plants, the results of testing of traffic on haul roads at a taconite mine (Test Series I), which was performed as part of another study, have also been added to the data base.[8] As shown in Table 2, in the tests conducted on a previously inactive road (Runs I-1 through I-5), emissions approached the predicted values with successive tests. The test truck was loaded between Runs I-3 and I-4. Also, measured emissions for Runs I-7 and I-8 were significantly lower than predicted, presumably because of the considerable rainfall on the days prior to testing.

OPEN DUST SOURCE: Vehicular Traffic on Unpaved Roads
QA RATING: B for Dry Conditions
C for Annual Average Conditions

$$\boxed{EF = 1.7 \left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right) \text{ kg/veh-km}}$$

$$EF = 5.9 \underbrace{\underbrace{\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)}_{\text{Determined by profiling of emissions from light-duty vehicles on gravel and dirt roads under dry conditions.}}\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}}_{\text{Determined by profiling of emissions from medium- and heavy-duty vehicles on gravel and dirt roads under dry conditions.}} \underbrace{\left(\frac{d}{365}\right)}_{\text{Estimated factor to account for mitigating effects of precipitation over period of one year.}} \text{ lb/veh-mi}$$

	metric	non-metric
EF = suspended particulate emissions	kg/veh-km	lb/veh-mi
s = silt content of road surface material	%	%
S = average vehicle speed	km/hr	mph
w = average number of wheels per vehicle	–	–
W = average vehicle weight	tonnes	tons
d = dry days per year	–	–

Figure 1. Predictive emission factor equation for vehicular traffic on unpaved roads.

TABLE 2. PREDICTED VERSUS ACTUAL EMISSIONS (UNPAVED ROADS)

	Road surface		Average vehicle speed		Average vehicle weight			Emission factor a/				
								Predicted b/		Actual		
Run	Type	Silt (%)	(km/hr)	(mph)	(tonnes)	(tons)	Average No. of vehicle wheels	(kg/VKT)	(lb/VMT)	(kg/VKT)	(lb/VMT)	Predicted ÷ actual
R-1	Crushed	12	48	30	3	3	4.0	1.7	5.9	1.7	6.0	0.98
R-2	Limestone	13	48	30	3	3	4.0	1.8	6.4	1.9	6.8	0.94
R-3		13	64	40	3	3	4.0	2.4	8.5	2.2	7.9	1.08
R-8		20	48	30	3	3	4.5	2.9	10.4	2.3	8.1	1.29
R-10	Dirt	5	64	40	3	3	4.0	0.93	3.3	1.1	3.9	0.85
R-13		68	48	30	3	3	4.0	9.3	33.0	9.0	32.0	1.03
A-14	Crushed	4.8	48	30	64	70	4.0	6.0	21.4	6.0	21.5	1.00
A-15	slag	4.8	48	30	64	70	4.0	6.0	21.4	6.5	23.0	0.93
E-1		8.7	23	14	31	34	9.4	4.7	16.7	3.8	13.6	1.23
E-2	Dirt	8.7	26	16	31	34	8.3	5.1	18.0	3.4	12.2	1.47
E-3		8.7	26	16	21	23	6.4	3.4	12.0	4.1	14.5	0.83
F-21	Dirt/	9.0	24	15	3	3	4.0	0.62	2.2	0.84	3.0	0.73
F-22	crushed	9.0	24	15	3	3	4.0	0.62	2.2	0.48	1.7	1.29
F-23	slag	9.0	24	15	4	4	4.1	0.76	2.7	0.65	2.3	1.19
F-24	Dirt/slag	0.03	24	15	3	3	4.0	d/	d/	0.021	0.073	-
F-25	(Coherex®) c/	0.02	24	15	3	3	4.0	d/	d/	0.10	0.36	-
G-27		5.3	35	22	15	17	11.0	3.0	10.7	3.4	12.0	0.89
G-28		5.3	37	23	11	12	9.5	2.3	8.1	2.0	7.2	1.13
G-29	Crushed	5.3	39	24	8	9	7.8	1.8	6.3	1.6	5.6	1.12
G-30	slag	4.3	40	25	13	14	8.5	2.1	7.5	2.4	8.7	0.87
G-31		4.3	47	29	7	8	6.2	1.4	6.1	1.4	5.1	0.99
G-32		4.3	35	22	27	30	13.0	3.9	14.0	4.5	16.0	0.88
I-1	Crushed	4.7	24	15	61	67	6.0	3.5	12.4	1.0	3.7	3.36
I-2	rock and	4.7	24	15	61	67	6.0	3.5	12.4	2.1	7.5	1.66
I-3 e/	glacial	4.7	24	15	61	67	6.0	3.5	12.4	4.1	14.5	0.86
I-4	till	4.7	24	15	142	157	6.0	6.4	22.6	5.1	18.1	1.25
I-5		4.7	24	15	142	157	6.0	6.4	22.6	7.0	25.0	0.90
I-7	Crushed	6.1	22	13.5	107	118	6.0	6.1	21.6	3.3	11.6	1.86
I-8 f/	rock (taconite/ waste)	6.1	22	13.5	106	117	6.0	6.1	21.5	3.3	11.6	1.85
I-9	Crushed	1.3	21	13	100	110	6.0	d/	d/	0.56	2.0	-
I-10	rock	1.5 g/	21	13	102	112	6.0	d/	d/	0.65	2.3	-
I-11	(TREX) c/	1.8	23	24	115	127	6.0	d/	d/	1.0	3.6	-

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a/ Particles smaller than 30 μm in Stokes diameter, based on actual density of silt particles.

b/ Based on revised MRI emission factor equation.

c/ Tests performed on treated road (see text).

d/ Equation not applicable.

e/ Test Series I-1 through 1-5 performed on previously inactive road.

f/ Tests performed on day following 2 days of rain totaling 1.13 in.

g/ Assumed value.

The wheel correction term appears in the emission factor equation for the first time. The need for this term was indicated by the fact that for Test Series E and G, the emission factor equation without a wheel correction term consistently underpredicted the measured factors. This appeared to be due to the effect of 10- and 18-wheel trucks, which comprised a substantial number of the passes in those tests. In all other test series, the vehicle mix was dominated by four- and six-wheel vehicles.

Excluding Test Series I except for Run Nos. I-3 and I-5, the revised emission factor equation presented in Figure 1 predicts actual test results with a precision factor of 1.48. (The precision factor (f) is defined such that the 95% confidence interval for a predicted emission factor value (P) extends from P/f to Pf.) By comparison, the precision factor for the unrevised equation is 1.66.

As stated above, limited testing of the effects of a chemical dust suppressant was also conducted. Coherex® (a petroleum-based emulsion) was used to treat a dirt/slag surfaced service road traveled by light- and medium-duty vehicles at an integrated iron and steel plant. Coherex® was applied at 10% strength in water.

Figure 2 shows a plot of measured dust control efficiency as a function of the number of vehicle passes following application of the road dust suppressant. Control efficiency was calculated by comparing controlled emissions with uncontrolled emissions measured prior to road surface treatment. As indicated, the effectiveness of the road dust suppressant was initially high but began to decay with road usage. It should also be noted that the apparent performance of Coherex® was negatively affected by tracking of material from the untreated road surface connected to the 100-m treated segment.

Figure 2 also shows the results obtained from the similar testing of another chemical dust suppressant at a taconite mine.[8/] TREX (ammonium) lignin sulfonate--a water soluble by-product of papermaking) was applied to the waste rock aggregate comprising the surface of a haul road. A 20 to 25% solution of TREX in water was sprayed on the road at a rate of 0.08 gal./sq yard of road surface.

Once again the effectiveness of the dust suppressant was found to be initially high, but decayed with road usage. According to taconite mine personnel, the binding effect of TREX can be partially restored by the addition of water to the road surface.

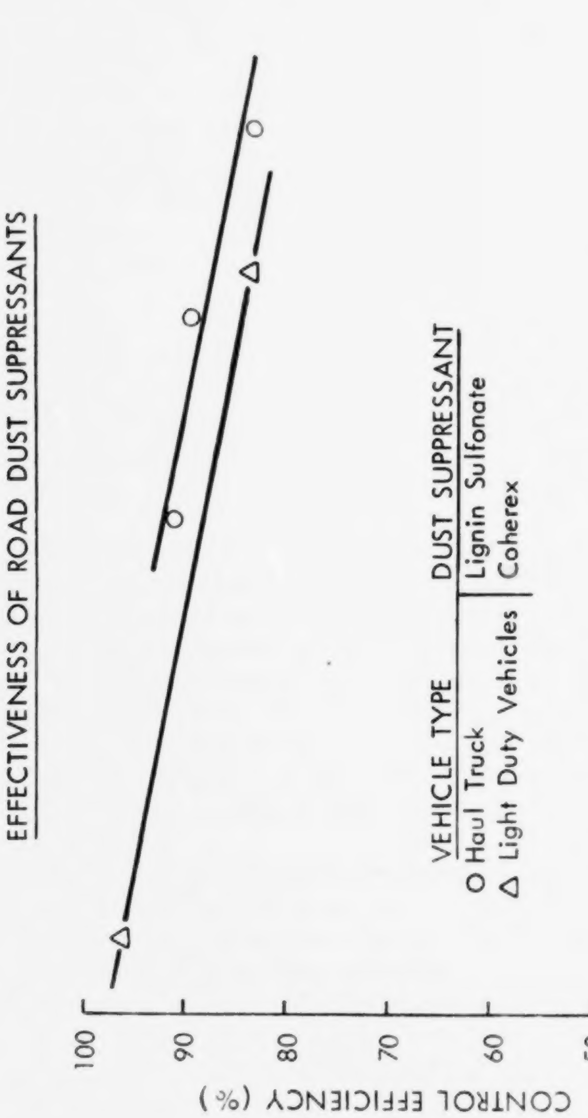

Figure 2. Effectiveness of road dust suppressants.

With regard to the effects of natural mitigation of road dust emissions, the final term in the emission factor equation for traffic on unpaved roads (Figure 1) is used to reduce emissions from dry conditions to annual average conditions. The simple assumption is made that emissions are negligible on days with measurable precipitation and are at a maximum on the rest of the days. Obviously, neither assumption is defendable alone; but there is a reasonable balancing effect. On the one hand, 0.01 in. of rain would have a negligible effect in reducing emissions on an otherwise dry, sunny day. On the other hand, even on dry days, emissions during early morning hours are reduced because of overnight condensation and upward migration of subsurface moisture; and on cloudy, humid days, road surface material tends to retain moisture. Further natural mitigation occurs because of snow cover and frozen surface conditions. In any case, further experimentation is needed to verify and refine this factor.

Vehicular Traffic on Paved Roads

Figure 3 shows the predictive emission factor formula for vehicular traffic on paved roads. As indicated, the coefficient and the first two correction terms were determined by field testing of emissions from traffic consisting primarily of light-duty vehicles on urban arterial roadways and on a test strip that was artificially loaded with surface dust in excess of normal levels.3/ The vehicle weight correction term was added by analogy to the experimentally determined factor for unpaved roadways, and more testing is needed to confirm the validity of this correction term. The number of lanes comprising the traveled portion of the road and over which the surface dust loading is distributed was added as a correction term to account for the fact that emissions increase in proportion to surface dust loading.3/

The industrial road correction factor was added to the emission factor equation because measured emissions from medium-duty and heavy-duty vehicles traveling on paved roadways at both Plant E (tested previously) and plant F were substantially in excess of the predicted levels without such a correction term. There are several plausible explanations for the increase in dust emissions from paved roads within integrated iron and steel plants as compared to urban roads. Paved roads within integrated iron and steel plants are typically bordered by unpaved surfaces and there are no curbings to prevent traffic from traveling on these surfaces. Therefore, additional dust generation may result from: (a) resuspension from vehicle underbodies of dust accumulated during travel over unpaved surfaces; (b) emissions from unpaved shoulders generated by the wakes of large vehicles; and (c) emissions from unpaved shoulders during passage of two large vehicles.

OPEN DUST SOURCE: Vehicular Traffic on Paved Roads
QA RATING: B for Normal Urban Traffic
C for Industrial Plant Traffic

$$\boxed{EF = 0.026\, I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \text{ kg/veh-km}}$$

$$EF = \underbrace{0.090}\,\underbrace{I}\,\underbrace{\left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1000}\right)}\underbrace{\left(\frac{W}{3}\right)}^{0.7} \text{ lb/veh-mi}$$

Determined by profiling of emissions from traffic (mostly light-duty) on arterial roadways with values for s and L assumed.

Assumed by analogy to experimentally determined factor for unpaved roads.

Determined by profiling of emissions from industrial plant traffic yielding higher than predicted emissions, presumably due to resuspension of dust from vehicle underbodies and from unpaved road shoulders.

Determined by profiling of emissions from light-duty vehicles on roadway which was artificially loaded with known quantities of gravel fines and pulverized topsoil.

	metric	non-metric
EF = suspended particulate emissions	kg/veh-km	lb/veh-mi
I = industrial road augmentation factor (see text)	-	-
n = number of traffic lanes	-	-
s = silt content of road surface material	%	%
L = surface dust loading on traveled portion of road	kg/km	lb/mi
W = average vehicle weight	tonnes	tons

Figure 3. Predictive emission factor equation for vehicular traffic on paved roads.

Also, there may be a wheel effect similar to that indicated for unpaved roads. Resuspension of dust from vehicle underbodies was visually evident at Plant E as the heavy-duty vehicles traveled from an unpaved area onto the paved roadway.

Quantification of these phenomena would require substantial additional testing with detailed analysis of site conditions and traffic patterns at test sites. For now, it is suggested that a multiplier of 7 be used with the emission factor equation when Item 1 above is readily observed and that a multiplier of 3.5 be used when the paved road (usually without curbs) is bordered by unpaved and unvegetated shoulders. These factors were determined by regression analysis of the test data for Plants E and F.

Table 3 compares measured emissions with predicted emissions as calculated from the equations given in Figure 3. The revised emission factor equation predicts actual test results with a precision factor of 3.31. This is a marked improvement over the precision factor of 14.1 associated with the unrevised equation.

It should be noted that the emission factor for re-entrained dust from paved roadways contains no correction term for precipitation. Although emissions from wet pavement are reduced, increased carryover of surface material by vehicles occurs during wet periods, and emissions reach a maximum when the pavement dries. More testing would be helpful in analyzing the net effects of precipitation on re-entrained dust emissions.

Storage Pile Formation by Continuous Load-In (Stacking)

Figure 4 gives the predictive emission factor equation for storage pile formation (load-in) by means of a translating conveyor stacker. The equation was originally developed from the results of field testing of emissions from the stacking of pelletized and lump iron ore at Plant A.[1/] The effect of wind speed on emissions occurs presumably because of the increased atmospheric exposure of suspendable particles during the drop from the stacker to the pile.

An additional adjustment term containing drop distance has been added to the emission factor equation. It was assumed that emissions are proportional to drop distance, accounting for the additional energy released on impact and the greater time of exposure during the drop.

TABLE 3. PREDICTED VERSUS ACTUAL EMISSIONS (PAVED ROADS)

Run	Type	Road surface dust: Loading excluding curbs[a/] (kg/km)	Road surface dust: Loading excluding curbs[a/] (lb/mile)	Road surface dust: No. of traffic lanes	Road surface dust: Silt (%)	I (industrial multiplier)	Average vehicle weight (tonnes)	Average vehicle weight (tons)	Emission factors[b/]: Predicted[c/] (kg/VKT)	Emission factors[b/]: Predicted[c/] (lb/VMT)	Emission factors[b/]: Actual (kg/VKT)	Emission factors[b/]: Actual (lb/VMT)	Predicted ÷ Actual
P-9	Pulverized topsoil[d/]	1,990	7,060	4	45	1	3	3	0.82	2.9	1.0	3.7	0.78
P-10		809	2,870	4	92	1	3	3	0.68	2.4	0.59	2.1	1.14
P-14	Gravel[d/]	1,890	6,700	4	23	1	3	3	0.39	1.4	0.13	0.46	3.04
E-7	(Iron and steel) Plant E	225	800	2	5.1	7	6	7	0.26	0.93	0.21	0.76	1.22
E-8		225	800	2	5.1	7	7	8	0.29	1.02	0.28	1.0	1.02
P-3, P-5, P-6	Urban arterial site 1[e/]	45.1[f/]	160[f/]	4	10[f/]	1	3	3	0.0039	0.014	0.0042	0.015	0.93
P-15, P-16	Urban arterial site 2[e/]	42.0[f/]	149[f/]	4	10[f/]	1	3	3	0.0037	0.013	0.0037	0.0130	1.00
F-13	Iron and steel plant	57.2	203	2	13.2	1	7	8	0.096	0.34	0.16	0.58	0.59
F-14		57.2	203	2	13.2	1	5	5	0.068	0.24	0.056	0.20	1.20
F-15		57.2	203	2	13.2	1	5	5	0.068	0.24	0.045	0.16	1.50
F-16	Iron and steel plant	629	2,230	2	6.8	3.5	12	13	0.76	2.7	0.70	2.5	1.08
F-17		629	2,230	2	6.8	3.5	11	12	0.70	2.5	0.48	1.7	1.47
F-18		629	2,230	2	6.8	1	5	5	0.11	0.39	0.14	0.48	0.81

[a/] Loading distributed over traveled portion of road, i.e., traffic lanes.

[b/] Particles smaller than 30 µm in Stokes diameter based on actual density of silt particles.

[c/] Based on revised MRI emission factor equation.

[d/] Four-lane test roadway artificially loaded.

[e/] Four-lane roadway with traffic count of about 10,000 vehicles per day, mostly light-duty.

[f/] Estimated value.

OPEN DUST SOURCE: Storage Pile Formation by Means of Conveyor Stacker

QA RATING: B

$$\boxed{EF = 0.00090 \, \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{3}\right)}{\left(\frac{M}{2}\right)^2} \text{ kg/tonne}}$$

$$\underbrace{EF = 0.0018 \, \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{10}\right)}{\left(\frac{M}{2}\right)^2} \text{ lb/ton}}$$

Determined by profiling of emissions from pile stacking of pelletized and lump iron ore and coal.

	metric	non-metric
EF = suspended particulate emissions	kg/tonne of material transferred	lb/ton of material transferred
s = silt content of aggregate	%	%
M = moisture content of aggregate	%	%
U = mean wind speed	m/sec	mph
H = drop height	m	ft

Figure 4. Predictive emission factor equation for storage pile formations by means of conveyor stacker.

Table 4 compares measured emissions with predicted emissions as calculated from the equation given in Figure 4. The revised emission factor equation predicts actual test results with an improved precision. However, the sample size remains too small for meaningful statistical determination of the precision factor.

Addition of the drop distance correction term aids significantly in predicting the results of Runs H-10 through H-12 although a large discrepancy remains for the first two of these runs. This may be due to lack of representativeness of the pellet moisture values for these runs. The pellets stacked during these runs comprised the last portion of a barge shipment, and moisture variations may have been substantial if water had collected in the bottom of the ship hold. The pellets were observed to be unusually wet when the samples were taken.

Wind Erosion

Twelve tests of wind erosion emissions were performed utilizing a portable wind tunnel with a specially designed isokinetic sampling system. Eight tests were performed on the upper flat surface of an inactive coal storage pile--three tests of one section of undisturbed (crusted) surface and five tests of a disturbed section. This was followed by two tests of the flat ground surface (undisturbed) adjacent to a dolomite storage pile and two tests of disturbed prairie soil in the same area. Both mass emission rates and particle size distributions were measured as a function of tunnel wind velocity. The wind erosion testing procedures are described elsewhere.[6/]

The results of the wind erosion testing indicated that natural surface crusts are very effective in mitigating suspended dust emissions. In addition, test data showed that a given surface has a finite potential for erosion prior to additional mechanical disturbance. As expected, erosion rates increase with wind velocity and decrease with erosion time as erodible material is depleted. Good agreement between measured emissions from an uncrusted coal surface and the previously developed emission factor equation only after the equation was modified to reflect the wind speed dependence of emission rate.[9/] Although the mitigating effect of surface crusted should be reflected in the reduced silt content of the surface material, which is taken into account in the previously developed emission factor equation, it is impossible to measure silt without destroying the surface crust. Therefore, an alternative approach is needed in modifying the equation to apply to crusted surfaces.

CONCLUSIONS

Based on an expanded data set of 24 tests, the revised MRI emission factor equation for traffic-entrained dust from unpaved roads predicts

TABLE 4. PREDICTED VERSUS ACTUAL EMISSIONS (LOAD-IN BY STACKER)

		Aggregate					Emission factor[a] x 10^3				
							Predicted[b]		Actual		
Run	Type	Silt (%)	Moisture (%)	Drop distance (m)	Wind speed (m/sec)	Wind speed (mph)	(kg/ tonne)	(lb/ ton)	(kg/ tonne)	(lb/ ton)	Predicted ÷ actual
A-8	Iron ore pellets	4.8	0.64	3.0	1.0	2.3	3.9	7.8	1.1	2.3	3.39
A-10		4.8	0.64	1.5	2.0	4.5	3.7	7.5	25.0	5.0	1.50
A-11	Lump iron ore	2.8	2.0[c]	4.5	0.8	1.8	0.27	0.54	0.26	0.53	1.02
A-12		11.9	4.3	3.0	0.8	1.8	0.16	0.33	0.19	0.38	0.87
A-13		19.1	4.3	3.5	1.0	2.2	0.38	0.76	0.12	0.25	3.04
H-10	Iron ore pellets	1.4	2.6	9.0	0.7	1.5	0.13	0.27	1.1	2.3	0.12
H-11		1.8	3.5	11.0	1.8	4.0	0.31	0.62	1.4	2.9	0.21
H-12		1.7	3.4	12.0	2.7	6.0	0.50	1.0	1.1	2.3	0.43
F-19	Coal	5.9	4.8	5.0	1.3	3.0	0.18	0.37	0.070	0.14	2.64

[a] Particles smaller than 30 µm in Stokes diameter based on an adjusted density of 2.5 g/cm^3; multiply emission factor values by 10^{-3} to obtain units given.

[b] Based on revised MRI emission factor equation.

[c] Estimated value.

measured emission factors with a precision factor of 1.48 as compared to a precision factor of 1.66 for the unrevised equation. The addition of a correction term related to the average number of wheels per vehicle reduced the mean prediction error, as suggested by the clear tendency of the unrevised equation to underpredict measured emission factors when the test road was traveled by a substantial portion of 10- and 18-wheel vehicles rather than 4- and 6-wheel vehicles.

Limited testing of chemical dust suppressants for industrial unpaved roads indicates a high initial control efficiency (exceeding 90%) which decreases by more than 10% with the passage of 200 to 300 vehicles. Consistent with the emission factor equation, the lowering of emissions is reflected by the reduced silt content of the road surface material after the application of chemical dust suppressants. Additional testing is needed to better quantify the performance of road dust suppressants. Testing is also needed to verify and/or refine the emission factor adjustment term which accounts for climatic mitigation.

The expanded test data set for traffic-generated dust from paved roads indicates that the unrevised MRI emission factor equation consistently underpredicts emissions (by up to a factor of 7) for industrial paved roads. This is thought to be due to the additional dust generation from unpaved areas adjacent to the paved surface. Incorporation of emission factor correction terms which account for emissions from unpaved shoulders and for the number of traffic lanes, improves the precision factor from 14.1 to 3.31.

Modification of the MRI emission factor equation for continuous drop operations (translating conveyor stacker) by the addition of a linear correction term involving drop distance aids in improvidng the predictive capability of the equation. However, predictive errors remain significant, which indicates effects of complex physical phenomena not accounted for in the emission factor equation.

The results of the wind erosion testing indicate that natural surface crusts are very effective in mitigating suspended dust emissions. This effect is not taken into account in the previously developed emission factor equation because the measurement of silt destroys the surface crust. In addition, test data show that a given surface has a finite potential for erosion prior to additional mechanical disturbance. As expected, erosion rates increase with wind velocity and decrease with erosion time, as erodible material is depleted.

ACKNOWLEDGEMENT

The work upon which this paper is based was performed in part pursuant to Contract No. 68-02-2609 with the U.S. Environmental Protection Agency (Robert V. Hendriks, Project Officer).

REFERENCES

1. Bohn, R., T. Cuscino, Jr., and C. Cowherd, Jr. Fugitive Emissions From Integrated Iron and Steel Plants. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-600/2-78-050, March 1978.

2. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-450/3-74-037, NTIS No. PB 238262/AS, June 1974.

3. Cowherd, C., Jr., C. M. Maxwell, and D. W. Nelson. Quantification of Dust Entrainment From Paved Roadways. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-450/3-77-027, July 1977.

4. Cowherd, C., Jr. Measurement of Fugitive Particulate. Second Symposium on Fugitive Emissions Measurement and Control, Houston, Texas, May 1977.

5. Cowherd, C., Jr., and C. M. Guenther. Development of a Methodology and Emission Inventory for Fugitive Dust for the Regional Air Pollution Study. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-450/3-76-003, January 1976.

6. Cowherd, C., Jr., R. Bohn, and T. Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation, Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-600/2-79-103, May 1979.

7. Mann, C. O., and C. Cowherd, Jr. Fugitive Dust Sources, Compilation of Air Pollution Emission Factors. Section 11.2, U.S. Environmental Protection Agency, Publication AP-42, NTIS No. PB 254274/AS, December 1975.

8. Cuscino, T., Jr. Taconite Mining Fugitive Emissions Study. Final Report, Midwest Research Institute for Minnesota Pollution Control Agency, June 7, 1979.

9. Cowherd, C., Jr. Development of Emission Factors for Wind Erosion of Aggregate Storage Piles. Paper No. 79-11.1 presented at the Annual Meeting of the Air Pollution Control Association, Cincinnati, Ohio, June 1979.

ESTIMATING FUGITIVE DUST CONTRIBUTIONS TO AMBIENT PARTICULATE LEVELS IN THE VICINITY OF STEEL MILLS BY USE OF A SNOW COVER CRITERION

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ABSTRACT

Suspended particulate measurements in Lake County Indiana were analyzed to determine the impact of two different source categories common in steel mills. These are ground-based non-traditional fugitive dust sources such as unpaved road traffic, material handling operations, storage piles, construction activity; and the more traditional sources such as stack emissions and industrial process fugitive particulate emissions.

The climatology and geography of the study area offer a perfect opportunity to evaluate the significance of the non-traditional sources. Three major integrated steel mills are situated along the southern shore of Lake Michigan with an open water fetch to the north and northeast. Under persistent onshore wind conditions, incoming background particulate levels are relatively low and levels measured near the mills are largely attributable to mill emissions.

Snow cover is common in Lake County winters and it suppresses fugitive dust emissions. Accordingly, under persistent onshore wind conditions, presence of snow cover was used as a criterion to assess the significance of the fugitive dust component of particulate emissions.

Suspended particulate data for Lake County were statistically analyzed first using broad meteorological and seasonal categories; concentrations on days with snow cover were found to be significantly lower than on days with bare ground. Limiting the analysis to cold season days with winds confined to a narrow onshore sector and moderate speeds clearly showed that concentrations were stratified by ground conditions.

Results of the narrowly-focused analysis indicate that, without snow cover and immediately downwind of the steel mills under the range of conditions studied, fugitive dust sources account for about half of measured levels, traditional sources account for about a third and background is responsible for the remaining one-fifth of total measured levels. The average contribution of traditional sources varies with location from 20 to 50 percent of total levels or from about 25 to 100 micrograms per cubic meter while the average contribution of fugitive dust sources varies with location from about 20 to 70 percent of total levels or from about 15 to 150 micrograms per cubic meter. These results strongly support air quality simulation modeling of mill emissions which indicates a comparable relationship between the contributions of traditional and fugitive dust sources.

ESTIMATING FUGITIVE DUST CONTRIBUTIONS TO AMBIENT PARTICULATE LEVELS IN THE VICINITY OF STEEL MILLS BY USE OF A SNOW COVER CRITERION

Fugitive dust has been generally acknowledged as a source of ambient particulate levels recorded by hi-vol samplers (References 1, 2). Fugitive dusts in industrial areas become airborne by processes such as (1) vehicles traveling over roads; (2) material handling operations such as loading and unloading of stock piles; (3) construction activity; and (4) turbulent eddy entrainment of dust over exposed ground.

The industrial geography and climatology of Lake County Indiana offer a unique opportunity to assess the significance of these sources on ambient total suspended particulate (TSP). Three major integrated steel mills are situated along the south shore of Lake Michigan in Lake County as shown on Figure 1. Local pollution control agencies operate hi-vol samplers on an every-sixth-day schedule at sites plotted in Figure 1. A detailed layout of storage piles and unpaved roads in one of the mills is shown on Figure 2. Advantage was taken of the local climatology and source-receptor geometry to establish the contribution of steel mill fugitive dust sources.

Traditional sources of suspended particulate in the steel mills can be expected to emit for the most part 24 hours a day, 365 days a year consistent with continuous operations characteristic of major steel mills. However, fugitive dust emissions are greatly affected by the weather.

Snow cover effectively suppresses fugitive dust emissions. Furthermore, existence of snow cover typically is an indication that exposed surfaces are wet or frozen--a state which also helps suppress fugitive dust emissions. Studies conducted by EPA Region V support this effect in showing a reduction of up to 90 percent in the concentration of certain constituents of typical ambient particulate levels (Reference 3), when the ground is snow covered. But while snow cover reduces or eliminates fugitive dust emissions, it has little effect on the emission rate of traditional sources.

Because snow cover eliminates or at least inhibits fugitive dust emissions and is frequent in the winter months in northern Lake County, analyses of TSP data were made using snow cover as an indicator for conditions under which the fugitive dust component of particulate emissions would be suppressed or eliminated. A statistical test metholology was established to determine whether significant differences in concentration data could be found on days when the ground was snow covered in comparison to levels found on days when the ground was bare.

The data base for this analysis consisted of measurements of 24-hour average TSP concentrations dating back to 1974 from a network of hi-vol samplers in northern Lake County and meteorological data from Midway Airport in Chicago. The principle meteorological data from Midway Airport was snow cover reported at 0600 CST and hourly winds and weather conditions. Days on which precipitation other than snow was recorded were eliminated from the analysis because precipitation might not only restrict fugitive dust emissions but also wash out categories of particulate emissions from the atmosphere and hence distort the results.

The analytical methodology consisted of constructing a null hypothesis in conventional statistical terms. Table 1 summarizes the hypothesis formulation. The question can be simply stated as follows: Is the average TSP concentration on days when the ground is snow covered equal to the average TSP concentration on days when the ground is bare? Again, the basic assumption is made that traditional particulate sources emit and affect ambient levels regardless of ground cover while, on the other hand, fugitive dust emissions are suppressed or eliminated when the ground is snow covered.

The analysis was restricted to colder months because of the reduced likelihood of lake breeze circulation influences and because background particulate levels in winter are inherently lower than those in summer for several reasons. First, photochemical and other atmospheric transformation processes are more effective in producing particulate levels from conversion of gaseous pollutants to particulate in summer compared to winter and, second, more frequent precipitation in winter reduces particulate levels by washout and rainout.

A statistical test was conducted on a data sample assembled under the following procedure:

1. sampling dates were restricted to the months of October through May;

2. resultant wind direction on the sampling date had to range

from north through northeast in which cases winds travel off Lake Michigan across the steel mills towards the samplers; and,

3. a date with snow cover was defined as one on which more than 1 inch of snow depth was reported at Midway at 0600 (CST) on the days before, during and after a TSP measurement.

The results summarized in Table 2 clearly indicate that recorded TSP levels near the steel mills were lower when the ground was snow covered compared to days when the ground was bare, apparently as a result of suppression or elimination of fugitive dust emissions by snow cover and/or frozen surfaces.

The analysis was taken one step further to assess the magnitude of contribution to recorded levels of the traditional and fugitive dust emissions from steel mills along the lakeshore by comparing in greater detail levels recorded at the nearest monitors on days with snow cover and days with bare ground.

The refined analysis was based on the key assumption that, at monitors near the lakeshore steel mills during the colder season days with north to northeast winds, concentrations recorded with snow cover resulted exclusively from traditional sources plus background while, with bare ground, concentrations were comprised of an identical contribution from traditional sources plus background and an additional contribution from fugitive dust emissions. The exact seasonal and meteorological criteria for selecting dates for this refined analysis were:

1. time period of October through May;

2. all wind directions during the entire day restricted to the range of 360° through 060° (north through northeast);

3. mean wind speed during the 24-hour period restricted to the range of 10 to 20 miles per hour (to avoid wide disparity in dispersion conditions); and,

4. snow cover restrictively defined as a minimum snow depth of 3 inches plus an increase in depth within 2 days of the TSP measurement to insure fresh snow cover.

This highly restrictive set of conditions for selecting a sample narrowed the number of days down to 4 with snow cover and 7 with bare ground. These data are summarized in Table 3.

Background on these days was estimated on the basis of recorded levels at monitoring stations at the South Water Filtration Plant in Chicago, which has an open exposure to Lake Michigan, and the Wirt School which lies at the extreme east end of Gary a half-mile south of the lakeshore with no significant sources between the monitor and the lakeshore. Again, the analytical methodology applied here is based on the following assumptions:

(1) on snow cover days, each recorded TSP concentration consisted of contributions only from traditional sources and background;

(2) on bare ground days, each recorded TSP level consisted of a contribution from traditional sources assumed equal to the average level on snow cover days, plus background and an increment from fugitive dust sources.

Background was assumed to be the arithmetic average of the concentrations recorded at the two background stations along the lakeshore. The calculation procedure is outlined in Table 4 and results are summarized in Table 5. The results of this analysis showed that, averaged over all monitoring sites, under the meteorological and seasonal restrictions imposed and conditioned on the assumptions made, traditional particulate emission sources account for about 50 micrograms per cubic meter and fugitive dust emission sources account for about 70 micrograms per cubic meter of total ambient TSP levels. In other words, fugitive dust sources contribute roughly a third more to ambient levels than traditional particulate sources. These results are consistent with air quality simulation modeling results which indicate similar relative contributions of traditional industrial particulate and fugitive dust sources.

Closer to the steel mills, the fugitive dust contribution increases relative to other sources while, farther away, it drops. At the site of highest relative impact, fugitive dusts comprise about two-thirds of average levels recorded when downwind of the mills.

DCL:mb

References

1. Control of Reentrained Dust from Paved Streets, Technical Report Data No. 907/9-77-007, National Technical Information Service, U. S. Department of Commerce (Springfield, VA., July 1977).

2. Guideline for Development of Control Strategies in Areas in with Fugitive Dust Problems, Technical Report Data No. EPA-450/2-77-029, National Technical Information Service, U. S. Department of Commerce (Springfield, VA., October 1977).

3. Air Programs Branch, Particulate Newsletter No. 5, United States Environmental Protection Agency, Region V (Chicago, ILL, 1979).

Reference 1

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
907/9-77-007

2.

3. RECIPIENT'S ACCESSION NO.
PB280325

4. TITLE AND SUBTITLE
Control of reentrained dust from paved streets

5. REPORT DATE
July 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Kenneth Axetell and Joan Zell

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

PEDCo-Environmental, Inc.
2480 Pershing Road
Kansas City, MO 64108

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
Contract No.
68-02-1375
Task order#35

12. SPONSORING AGENCY NAME AND ADDRESS

U.S.Environmental Protection Agency
Region VII - Air Support Branch
1735 Baltimore
Kansas City, MO 64108

13. TYPE OF REPORT AND PERIOD COVERED
Final Report 6/76-7/77

14. SPONSORING AGENCY CODE
EPA-Region VII and OAQPS
927/20

15. SUPPLEMENTARY NOTES
Region VII project officer for this report was Dewayne E. Durst, 1735 Baltimore, Kansas City, Missouri, 64108

16. ABSTRACT

The report is a comprehensive review of the problem of reentrained dust from paved streets. Information was obtained from literature review, collection of unpublished data from traffic-related air and water pollution studies, survey of comments from public works officials, and five different field studies to evaluate the effectiveness of specific reentrained dust control measures. All of the assembled data show agreement that the effect of traffic-related particulate emissions in the form of reentrained dust is one of the most important sources of particulate matter in metropolitan areas. The results of the field studies conducted in the project and analysis of six other studies were inconclusive with regard to the effectiveness of improved street cleaning as a means of improving air quality. None of the street cleaning methods proved to be effective in all studies in which they were evaluated. In addition, the data generated in the field studies did not show a consistent relationship between street surface loadings and nearby particulate concentrations. The report gives information on the costs for conventional street cleaning operations and possible modifications to improve air quality. Examples of existing state and local regulations and ordinances for controlling reentrained dust are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
air pollution traffic volume suspended particulates urban fugitive dust reentrained dust street cleaning Regulations	air pollution control mobil sources fugitive emissions particulates	

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT
Release unlimited

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

22. PRICE
A10 - A01

EPA Form 2220-1 (9-73)

Reference 2

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-450/2-77-029

2.

3. RECIPIENT'S ACCESSION NO.
PB275474

4. TITLE AND SUBTITLE
Guideline for Development of Control Strategies in Areas in with Fugitive Dust Problems -

5. REPORT DATE
October, 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
George Richard, TRW
Dallas Safriet, EPA

9. PERFORMING ORGANIZATION NAME AND ADDRESS
TRW
Environment Engineering Division
One Space Park
Redondo Beach, California

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-01-3152

12. SPONSORING AGENCY NAME AND ADDRESS
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Monitoring and Data Analysis Division
Research Triangle Park, North Carolina 27711

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The document outlines a methodology for development of control strategies for areas experiencing non-attainment problems due to fugitive dust emissions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Particulate Matter Total Suspended Particulate Emission Sources Control Methods Fugitive Dust Air Quality Measurement Air Quality Modeling		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC A05 MF A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

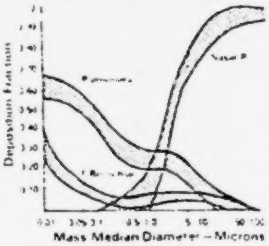
United States
Environmental Protection
Agency

Region V
230 South Dearborn
Chicago, Illinois 60604

Reference 3

Air Programs Branch
Number 5
FEBRUARY MARCH 1979 *

EPA PARTICULATE NEWSLETTER



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General USEPA Malfunction Policy

The USEPA malfunction policy was stated in the Utah Implementation Plan for Sulfur Dioxide relating to Kennecott Copper Corporation's smelter located in Salt Lake City, Utah, (42 FR 21472). Basically, the policy is that all excess emissions are violations of the applicable emission standards with no automatic exemptions. However, the USEPA doesn't desire to penalize the prudent operator for emissions that are beyond the operator's control but would use enforcement discretion depending on the circumstances. USEPA recognizes that the frequency of incidences and the quantity of the excess emissions could be reduced by good operation and maintenance including a comprehensive preventive maintenance program. With such a program, the existing air pollution control equipment will provide its maximum benefit and return on investment.......Onsgard

Particulate Controls for Stoker Fired Boilers

On January 31, 1979, Messrs; Ed Piasecki and Dave Skivens of General Motors Environmental Activities Staff gave a presentation on various operating practices and controls used in various GM facilities to a group of engineers with the Engineering Unit. The following is a summary of their remarks:

1. Uncontrolled emissions increase as the percentage of fines (i.e. size below 10 microns) in the coal increase. GM facilities try to limit this to no more than 20%.
2. Uncontrolled emissions increase as excess air in the boiler increases. This should be as low as possible to support complete combustion.
3. Uncontrolled emissions increase as % over-fire air decreases.
4. With newer types of multicyclones, i.e. with two sets of vanes and higher pressure drops, GM facilities can meet 0.3 pounds per million BTU heat input with the above operating practices and if coal quality is such that higher heating value and ash content are 12500 BTU/lb. and 6 to 8%, respectively.
5. GM has been working on a side stream separator (see following story) which should be able to reduce emissions to below 0.2 pounds per million BTU heat input at a fraction of the cost it takes to install baghouses or precipitators........Goklany

*Our issues to date have been: Nov. 1978 - Number 1
Dec. 1978 - Number 2
Jan. 1979 - Number 4

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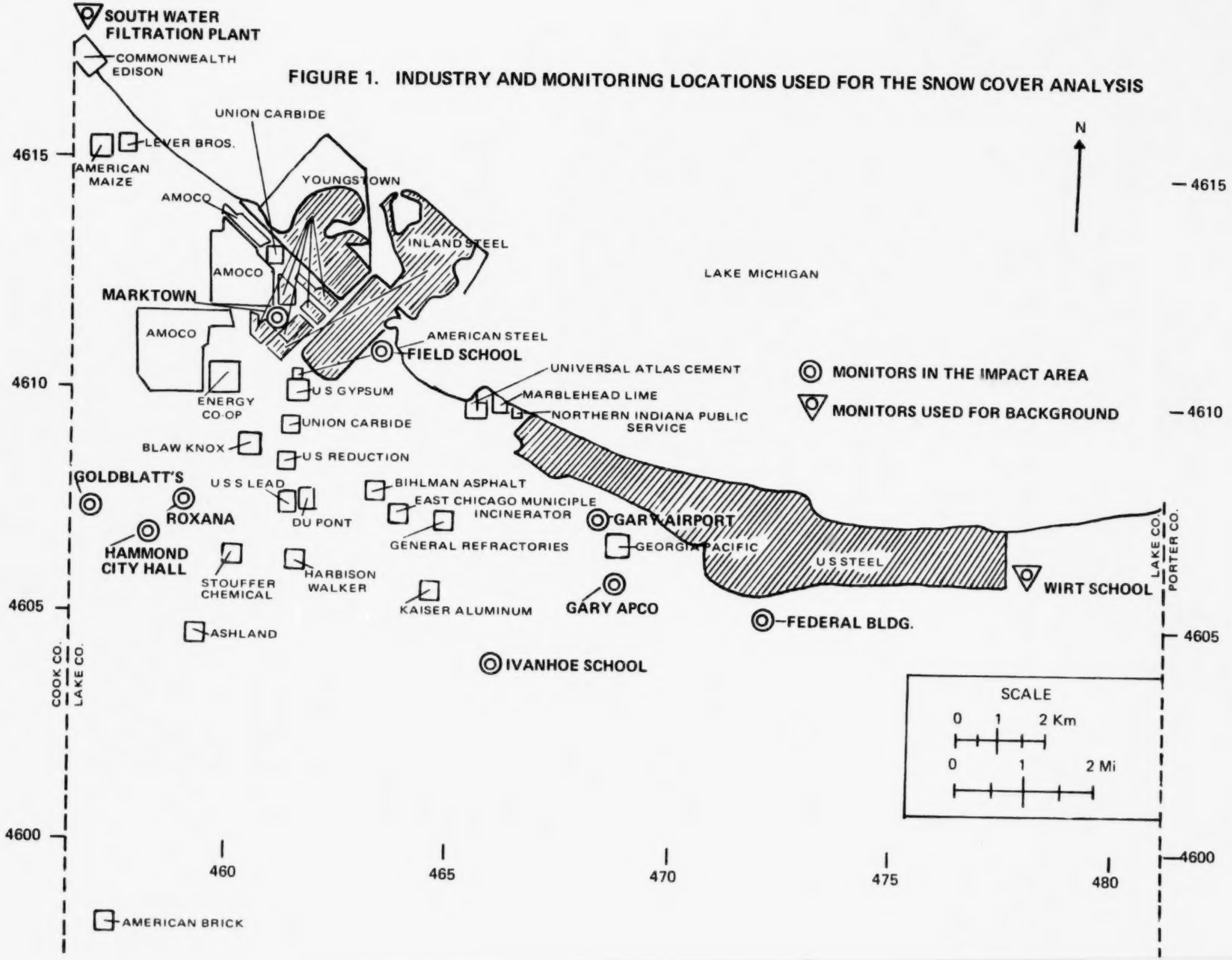
FIGURE 1. INDUSTRY AND MONITORING LOCATIONS USED FOR THE SNOW COVER ANALYSIS


SOUTH WATER FILTRATION PLANT
COMMONWEALTH EDISON
UNION CARBIDE
LEVER BROS.
AMERICAN MAIZE
AMOCO
YOUNGSTOWN
INLAND STEEL
AMOCO
MARKTOWN
AMOCO
AMERICAN STEEL
FIELD SCHOOL
UNIVERSAL ATLAS CEMENT
MARBLEHEAD LIME
NORTHERN INDIANA PUBLIC SERVICE
LAKE MICHIGAN
N
MONITORS IN THE IMPACT AREA
MONITORS USED FOR BACKGROUND
ENERGY CO-OP
U S GYPSUM
UNION CARBIDE
BLAW KNOX
U S REDUCTION
GOLDBLATT'S
U S S LEAD
BIHLMAN ASPHALT
EAST CHICAGO MUNICIPLE INCINERATOR
ROXANA
DU PONT
HAMMOND CITY HALL
GENERAL REFRACTORIES
GARY AIRPORT
GEORGIA PACIFIC
U S STEEL
WIRT SCHOOL
STOUFFER CHEMICAL
HARBISON WALKER
KAISER ALUMINUM
GARY APCO
FEDERAL BLDG.
ASHLAND
IVANHOE SCHOOL
COOK CO.
LAKE CO.
LAKE CO.
PORTER CO.
SCALE
0 1 2 Km
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4615
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AMERICAN BRICK

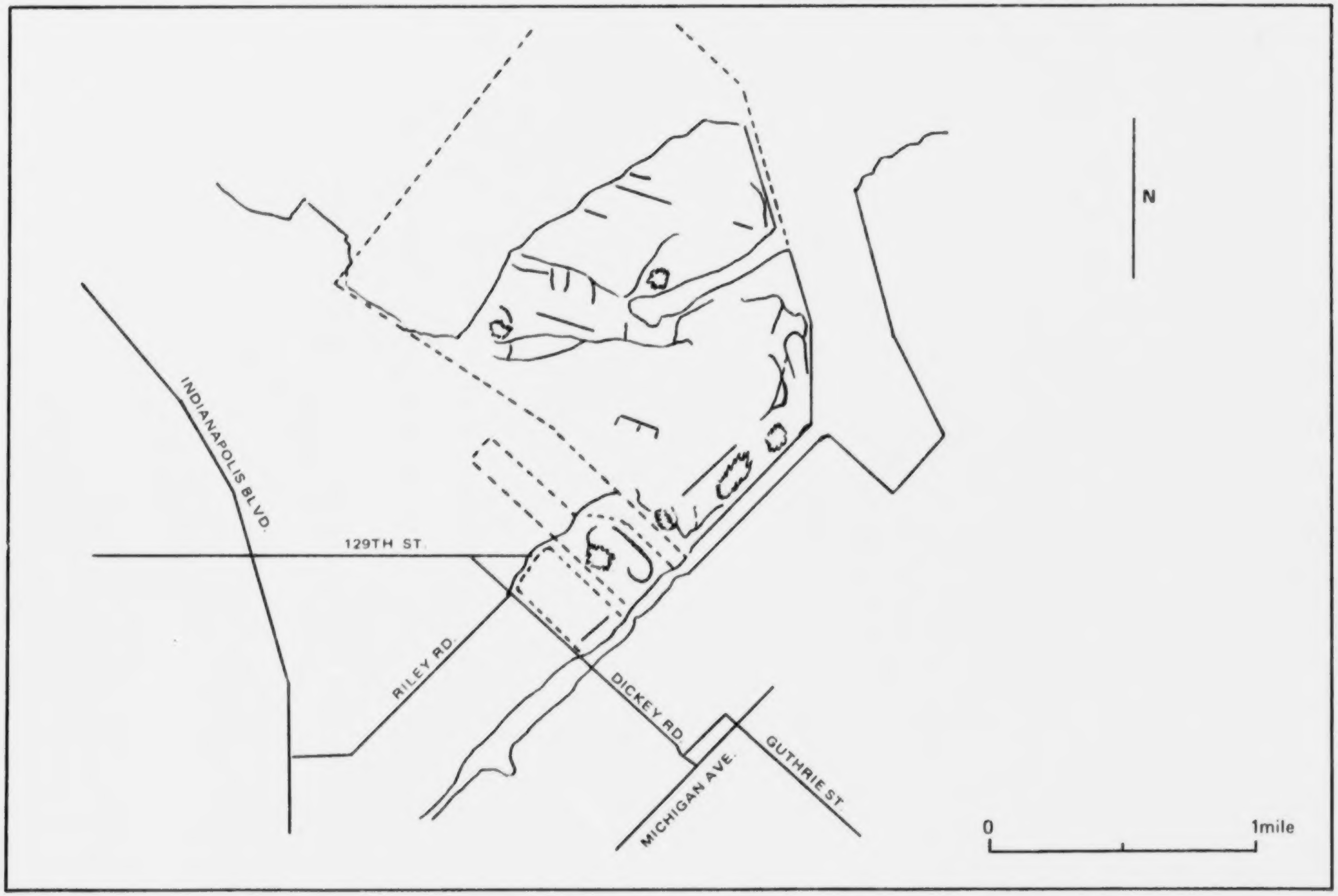
N
INDIANAPOLIS BLVD.
129TH ST.
RILEY RD.
DICKEY RD.
MICHIGAN AVE.
GUTHRIE ST
0
1mile

FIGURE 2. MAP OF UNPAVED ROADS AND STORAGE PILES IN EMISSION INVENTORY

TABLE 1

HYPOTHESIS FORMULATION

Null Hypothesis, H_o = The mean of TSP concentrations recorded on snow cover days is equal to the mean of TSP concentrations recorded on bare ground days.

Level of significance, $\alpha = .01$

$$Z \text{ Statistic} = \left(\bar{X}_1 - \bar{X}_2\right) \Big/ \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$$

where $\bar{X}_1$ = mean of all TSP concentrations recorded on bare ground days

$\bar{X}_2$ = mean of all TSP concentrations recorded on snow cover days

σ_1 = standard deviation of TSP concentrations recorded on bare ground days

σ_2 = standard deviation of TSP concentrations recorded on snow cover days

N_1 = sample size (number of 24-hour average TSP concentration measurements) on bare ground days

N_2 = sample size (number of 24-hour average TSP concentration measurements) on snow cover days.

For a one-tailed test if the "Z" statistic is greater than 2.33 reject the null hypothesis.

TABLE 2

HYPOTHESIS TEST RESULTS*

$\overline{X}_1$	$\overline{X}_2$	σ_1	σ_2	N_1	N_2	Z
132.8	74.1	64.6	35.9	66	37	5.93

Conclusion:

Reject null hypothesis, TSP concentrations on snow cover days are significantly lower than TSP concentrations on bare ground days.

* See Table 1 for explanation of symbols.

TABLE 3

LISTING OF DATA FOR SNOW COVER AND BARE GROUND DAYS UNDER RESTRICTIVE METEOROLOGICAL CONDITION

	Snow Cover Days				Bare Ground Days						
DATE	1/25/76	1/14/78	1/20/78	2/13/78	3/13/75	4/24/75	5/16/75	5/24/76	5/7/77	10/29/77	4/26
Resultant Wind (degrees) Direction	50	10	20	50	10	30	40	10	20	40	20
Average Wind Speed (MPH)	10.1	14.7	16.4	16.0	13.2	13.4	9.8	14.4	12.4	10.4	13
Day of Week	Sun	Sat	Fri	Mon	Thu	Thu	Tue	Mon	Sat	Fri	We
Monitor Site	μg/m³										
South Water Filter Plant	-	21	22	23	23	39	22	-	-	-	25
Wirt School	39	45	34	56	21	44	27	15	35	46	3
Average Background	39	33	28	39.5	22	41.5	24.5	15	35	46	27.
Marktown	127	94	63	124	124	-	97	68	46	170	115
Gary Airport	59	54	68	-	120	-	-	258	79	78	147
Federal Bldg.	102	113	187	164	-	-	-	206	242	174	525
Gary APCO	79	68	61	90	89	85	47	169	69	98	117
Field School	104	118	92	47	184	271	226	420	292	-	288
Roxanna	89	49	100	-	-	135	83	78	67	271	244
Hammond City Hall	64	72	85	-	71	49	123	72	61	136	-
Goldblatts	65	56	68	108	71	-	74	66	183	247	-
Ivanhoe School	82	64	71	94	72	108	83	342	88	72	118

TABLE 4

CALCULATION PROCEDURE FOR ESTIMATING SOURCE CONTRIBUTIONS AT EACH MONITORING SITE

$$T = \frac{\sum^{N_s} (C_{Si} - b_i)}{N_s}$$

C_s = recorded ambient TSP concentration on snow cover day, i ($\mu g/m^3$)

b = average background TSP concentration on snow cover day, i ($\mu g/m^3$)

N_s = number of days of both C_s and b available in pairs

T = estimated contribution of traditional sources ($\mu g/m^3$)

$$F = \frac{\sum^{N_B} (C_{Bi} - b_i) - T}{N_B}$$

C_B = recorded ambient TSP concentration on bare ground day, i ($\mu g/m^3$)

b = average background TSP concentration on bare ground day, i ($\mu g/m^3$)

N_B = number of days of both C_B and b available in pairs

F = estimated contribution of fugitive dust sources ($\mu g/m^3$)

$$B = \sum^{N_{SB}} b_i \Big/ (N_S + N_B)$$

B = estimated contribution of background ($\mu g/m^3$)

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TABLE 5

CALCULATION OF ESTIMATED TRADITIONAL SOURCE FUGITIVE DUST SOURCE AND BACKGROUND PARTICULATE LEVELS UNDER RESTRICTIVE METEOROLOGICAL CONDITIONS

	Estimated Contribution of Source**					
	Traditional Sources		Fugitive Dust Sources		Background	
Site/Parameter	T ($\mu g/m^3$)	Per-cent	F ($\mu g/m^3$)	Per-cent	B ($\mu g/m^3$)	Per-cent
Marktown	67	52	30	23	32	25
Gary Airport	27	19	84	59	31	22
Federal Building	107	37	148	51	33	12
Gary APCO	40	45	16	18	32	37
Field School	55	23	157	65	30	12
Roxanna	46	31	68	46	33	23
Hammond City Hall	40	47	16	19	30	34
Goldblatt's	39	29	65	48	31	23
Ivanhoe School	43	34	52	41	32	25
Group Mean of Monitor Sites Closest to Industrial Areas	59	33	87	49	32	18
Group Mean of Monitor Sites Farthest from Industrial Areas	42	34	50	40	32	26
Average of All Sites	52	33	71	46	32	21

** See Table 4 for explanation of letter symbols.

SINTER PLANT WINDBOX GAS RECIRCULATION
AND
GRAVEL BED FILTRATION DEMONSTRATION

BY

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26062

ABSTRACT

This research program was initiated with the overall objective of developing new technology for the reduction of exhaust gas volume and the control of emissions from the sintering process in the steel industry. This paper documents the operating problems, as well as the environmental, energy and economic relationships associated with the Sinter Plant windbox gas recirculation and gravel bed filtration. At this point in time, an overall evaluation indicates both strong advantages and serious disadvantages in these technologies. It has been demonstrated that the pollutant mass emission reduction achieved by windbox gas recirculation is principally a function of the percentage of waste gas volume recycled. It has also been demonstrated that windbox gas recirculation and gravel bed filtration are compatible technologies. However, recycle limitations in the windbox gas recirculation system, and filter media support screen blinding in the gravel bed filter system are problems not yet totally resolved. The relative merits of these technologies cannot be established until total optimization of these facilities is achieved. For this reason, recommendations concerning the acceptability of these technologies are reserved until a later date.

PRESENTED AT THE EPA SYMPOSIUM ON IRON AND STEEL
POLLUTION ABATEMENT TECHNOLOGY

Pick-Congress Hotel
Chicago, Illinois

October 30, 31 and November 1, 1979

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RESEARCH TRIANGLE PARK, N. C. 27711

SINTER PLANT WINDBOX GAS RECIRCULATION AND GRAVEL BED FILTRATION DEMONSTRATION

INTRODUCTION

The sintering process is utilized by the steel industry to agglomerate large quantities of iron ore fines and steel mill waste iron oxides into a suitable raw material for the production of iron in a blast furnace. In essence, a sintering plant is a solid waste recovery facility which conserves our natural resources and eliminates a solid waste disposal problem. The first step in the production of sinter involves the mixing of ore fines, thickener sludge, iron scale, and other iron-bearing waste material with coke breeze and limestone to form a mass which can be ignited to produce an aggregate. The coke breeze is added to provide the required fuel for downdraft combustion in the sintering process, while the limestone provides the necessary flux for the sinter when it is subsequently processed in the blast furnace. These materials, which make up the burden to the sinter machine, are passed through a balling drum to blend and agglomerate the constituents into a permeable mixture which will result in rapid and uniform sintering.

After blending, the mixture is charged onto a traveling grate (sintering machine). Near the entry or feed end of the machine, the bed is ignited on the surface by gas burners in a furnace, and as the mixture moves along on the traveling grate, air is continuously drawn through the bed to support the combustion of the material. The combustion process progresses downward through the bed at a temperature of approximately 1500° C. until the entire depth of the charged material is sintered. The moving grate then discharges the sintered material for further processing and subsequent charging into the blast furnace.

Excess air plus the combustion products and unagglomerated particulate matter are drawn through the sintering bed by induced draft fans and enter large chambers located under the moving grates. These chambers, which run the length of the machine are referred to as windboxes. Typically a dual arrangement of twelve to sixteen windboxes is located under the sinter machine. Each windbox is equipped with facilities to discharge and return to the plant the larger particulate matter which has been drawn through the grates and collected in the windboxes. However, approximately twenty pounds of particulate matter per ton of sinter strand feed, remains airborne and passes through the windbox system.

Control of these particulate emissions from the main windbox system is a difficult problem. While technically feasible control processes exist, improvements to present technology are needed to achieve more effective, reliable and economical control of these emissions. Due to the high percentage of windbox particulate emissions under ten microns in size, cyclone and multiclone installations have been proven inadequate in this application. High moisture, acid salts and condensable hydrocarbons in the windbox discharge can cause serious operating problems in baghouse, wet scrubber and dry and wet electrostatic precipitator installations. Further disadvantages are associated with the wet-type control technologies due to the related corrosion and water pollution control problems.

Preliminary investigation by National Steel Corporation had indicated that recirculation of a portion of the gases generated in the windbox system of the sintering process may significantly reduce particulate and hydrocarbon emissions to the atmosphere. Further work completed by the Company, under the partial sponsorship of the Federal Environmental Protection Agency, developed the engineering and design for the installation of this technology on the Weirton Steel Division No. 2 Sinter Machine. This information was contained in a report titled "Sinter Plant Windbox Gas Recirculation System Engineering and Design" which was published by the Environmental Protection Agency in August of 1975 (available from NTIS as Report No. PB249-546A5).

Preliminary investigation by the Company had also indicated, on a pilot scale, that gravel bed filtration can remove main windbox particulate emissions with the presence of condensable hydrocarbons in the gas stream. Based on these investigations, the technologies of windbox gas recirculation and gravel bed filtration were recommended for full scale evaluation.

WINDBOX GAS RECIRCULATION SYSTEM

Description of Recirculation System

Windbox gas recirculation, as applied to a sinter plant, involves the return of a portion of the windbox exhaust gas to a hood above the sinter bed. The objective is to reduce the volume of waste gas to be cleaned and to conserve a part of the sensible heat in the windbox exhaust gas. The portion of gas recycled to the machine must pass through the heat zone of the sinter bed thus providing the potential for the reduction of hydrocarbons through carbonization.

Figure No. 1 illustrates the general arrangement of the Weirton Steel Division Sinter Plant Gas Recirculation System. The effluent gases and particulate matter exhausted from the sinter bed enter the dual arrangementof fourteen windboxes under the sinter strand, and pass through downcomers to two parallel waste gas mains on the east and west sides of the machine. Each waste gas main transports approximately fifty percent of the sinter machine windbox effluent to a series of four cyclone dust collectors for the removal of the larger particulate matter. From the cyclones, the windbox effluent re-combines in a plenum chamber for distribution to the two induced draft fans operating parallel. Each fan was designed to exhaust approximately 11,000 cubic meters per minute at a temperature of 200° C. and a static pressure of 1300 millimeters water column.

The waste gas fan exhausts fifty percent of the total gas volume from the plenum chamber and delivers it to the gravel bed filter system. The recycle gas fan exhausts the remaining fifty percent of the gas volume from the plenum chamber, and recirculates a portion of the total gas volume to the sinter machine via an insulated recycle gas main, six distribution ducts, and a modular recycle hood which extends from the ignition furnace to the sinter breaker. The modular recycle hood is designed for quick removal of individual sections to facilitate maintenance. The system was designed to recirculate 39 percent of the total windbox exhaust volume.

Windbox Gas Recirculation System Operating Problems

The installation of a recirculation system for a sinter machine can result in serious operational problems in that the system becomes an integrated part of the sintering process. Although concessions were required with regard to the maintenance and operation of the sinter machine, satisfactory performance has been achieved in all but one area which has prevented the achievement of the design recirculation rate. This problem area concerns the expulsion of particulate and gases from under the sinter machine recycle hood.

During the design phase of this system, it was anticipated that the percentage of waste gas returned to the machine would be limited by its oxygen content. However, in actual practice it was found that recycle rates higher than twenty-five percent resulted in ambient air quality problems in the operating area. At thirty percent recycle, significant quantities of particulate and gas were discharged into the plant at several locations along the perimeter of the hood system.

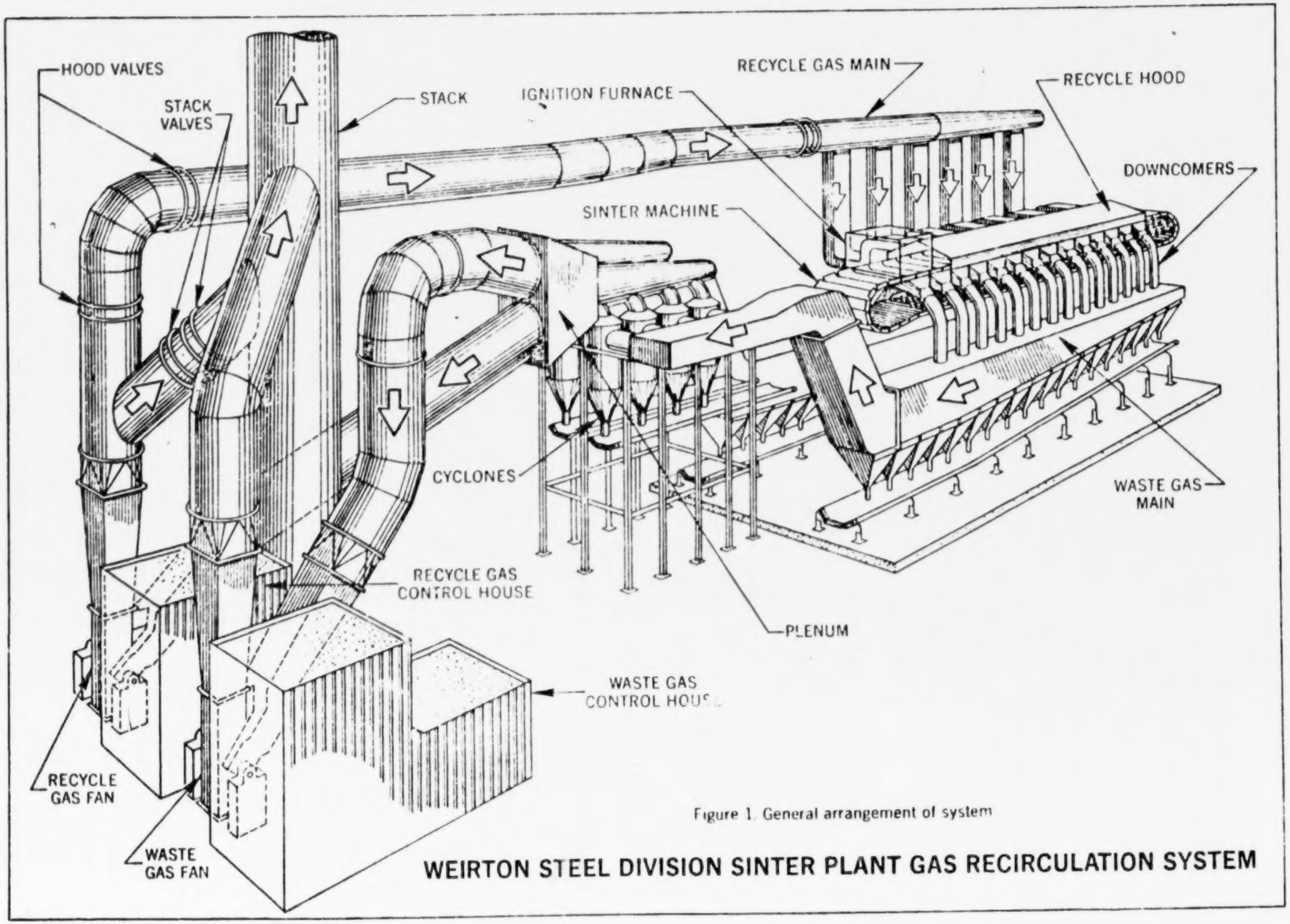

HOOD VALVES
STACK VALVES
STACK
IGNITION FURNACE
RECYCLE GAS MAIN
RECYCLE HOOD
DOWNCOMERS
SINTER MACHINE
CYCLONES
WASTE GAS MAIN
RECYCLE GAS CONTROL HOUSE
PLENUM
WASTE GAS CONTROL HOUSE
RECYCLE GAS FAN
WASTE GAS FAN
WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM

Figure 1. General arrangement of system

The reasons for the recirculation limitation of twenty-five percent are not totally known at this time, but the major contributing factor is excessive leakage at the windbox system. It is estimated that excess air at the rate of fifty percent of the total effluent volume is entering the windbox system via routes other than through the sinter bed. This condition is not uncommon in older sinter machines, since the economic advantage of minimal leakage was not apparent until the 1970's. In an effort to decrease the leakage rate, increase the windbox recirculation rate and further reduce the requirements for the final air pollution control device, the Company has initiated programs for improved sealing facilities at the pallet train and windbox junctures of the sinter machine. In addition, an aggressive maintenance program has been established for the repair of leakage in the windbox, collecting main and cyclone systems. Repair of leakage from erosion in these areas is a never-ending, but essential, task.

In order to determine any significant differences in the operating parameters and product quality derived from the utilization of windbox gas recirculation, tests were conducted under both conventional operation and maximum permissible waste gas recirculation to the sinter strand. Although the oxygen content of the windbox gas decreased from sixteen percent to fourteen percent, no significant problems resulted while operating in the recirculation mode. Sinter quality was identical during the two periods, and it was concluded that the utilization of waste gas recirculation at a rate of twenty-five percent has no significant effect on the chemical or physical properties of the sinter.

Windbox Gas Recirculation System Environmental Concepts

An environmental testing program was conducted by Weirton Steel Division to determine the effectiveness of the windbox gas recirculation system (see Table 1). The test program was designed to document a direct comparison of non-recycle and recycle operation of the sinter machine. Due to the variability of the raw material charge to the sinter machine, it was concluded that the non-recycle and recycle modes should be sampled on the same day. Sufficient time was permitted after the change-over of each mode of operation to permit stabilization of the process. The Environmental Protection Agency approved methods of sampling were utilized in all cases except the measurement of condensable hydrocarbons, where there is no approved method. In this case, the Environmental Protection Agency draft method was employed.

The testing program indicated that a twenty-five percent recirculation rate results in a 32.2 percent mass reduction in particulate emissions, a 17.4 percent mass reduction in sulfur dioxide emissions and a 31.6 percent mass reduction in condensable hydrocarbon emissions. An analysis of the test results reveals that the reductions in mass emissions for the parameters are principally a function of the percentage of waste gas recycled. Only minor changes in the concentration of these parameters were noted between the non-recycle and recycle operational modes. A 7.4 percent decrease in particulate concentration was documented under recycle conditions,

TABLE NO. 1

SINTER PLANT WINDBOX GAS RECIRCULATION TEST RESULTS

Parameter	Without Windbox Recirculation	With 25% Windbox Recirculation	Percent Change
Particulate Matter			
Concentration (mg/Nm^3 Gas)	1182	1094	- 7.4
Mass Emission Rate (g/kg Sinter Strand Feed)	3.20	2.17	-32.2
Sulfur Dioxide			
Concentration (mg/Nm^3 Gas)	320	350	+ 9.4
Mass Emission Rate (g/kg Sinter Strand Feed)	0.86	0.71	-17.4
Condensible Hydrocarbons			
Concentration (mg/Nm^3 Gas)	7.0	6.4	- 8.6
Mass Emission Rate (g/kg Sinter Strand Feed)	0.019	0.013	-31.6

however, this difference is considered to be within the normal deviation for Method 5 stack sampling determinations. The 9.4 percent increase in sulfur dioxide concentration, along with the lower 17.4 percent mass reduction, indicates a build-up of this gas within the system which is to be expected. The 8.6 percent reduction in condensable hydrocarbon concentration was somewhat disappointing. Attempts to perform material balances by analyzing feed and product samples during the non-recycle and recycle modes of operation produced mixed results. It is interesting to note that under either mode of operation, more than 85 percent of the hydrocarbon input loading was destroyed by the sintering process. However, in view of the questions concerning condensable hydrocarbon sampling and analyses procedures, and the inconsistencies in the data generated in the test program, it must be emphasized that any judgements concerning this parameter must be made cautiously.

Windbox Gas Recirculation System Energy Consumption

The replacement of two existing 2500 horsepower fans with two new 4500 horsepower fans is a major consideration in the analysis of the energy aspects of this system. The new fans were installed to accommodate (1) the increased windbox gas volume due to the anticipated elevation in windbox gas temperature, and (2) the additional resistance of the new ductwork from the recycle fan to the sinter machine hoods.

In actual operating practice, the anticipated elevation in windbox gas temperature did not occur. The design calculations were based on a windbox gas temperature of 200° C., whereas a temperature averaging approximately 120° C. was documented after the system was commissioned. This lower temperature was a result of an adjustment in the quantity of coke breeze in the sinter burden, which was necessitated by excessive sinter bed temperature. To alleviate the excessive bed temperature and associated operating and maintenance problems, the quantity of coke breeze in the burden was reduced by seven percent. Thus, during actual operation, the temperature below the strand burden is essentially the same with or without recirculation.

Energy data for the Sinter Plant were tabulated from the Company's monthly energy reports for reference periods before and after the installation of the windbox gas recirculation system (see Table 2). As a result of the fan replacement, electrical power consumption increased 77 joules/m.t. of sinter or fifty-four percent. As expected, the coke-oven gas consumption remained constant before and after the installation. With recirculation, the coke breeze consumption decreased 146 joules/m.t. of sinter or seven percent. As stated previously, this adjustment was necessary to eliminate the problems associated with excessive sinter temperature. The total energy consumption per unit of sinter production decreased 69 joules/m.t. or three percent from 2510 joules/m.t. prior to recirculation to 2441 joules/m.t. after recirculation. The decrease in the energy requirement can be attributed to the recovery of waste heat from the recirculated waste gas and the reduction in coke breeze consumption. These data can be very misleading if taken out of context. While it is true that the windbox gas recirculation permits the recovery of waste heat, the fact remains that an inexpensive source of energy (coke breeze) is being

TABLE NO. 2

SINTER PLANT ENERGY CONSUMPTION PER UNIT OF SINTER PRODUCTION

	Electricity	Coke Oven/ Natural Gas	Coke Breeze	TOTAL
Sinter Plant Energy Consumption Without Windbox Recirculation and Gravel Bed Filtration (joules/m.t.)	143	221	2146	2510
Sinter Plant Energy Consumption with Windbox Recirculation (joules/m.t.)	220	221	2000	2441
Energy Consumption by Windbox Gas Recirculation System (joules/m.t.)	77	0	-146	- 69
% Change	54%	0	- 7%	- 3%
Sinter Plant Energy Consumption with Windbox Gas Recirculation and Gravel Bed Filtration (joules/m.t.)	266	268	2000	2534
Energy Consumption of Gravel Bed Filter System (with 60% of Effluent Volume) (joules/m.t.)	46	47	0	93
% Change	32%	21%	0	4%
Energy Consumption of Combined Systems (joules/m.t.)	123	47	-146	24
% Change	86%	21%	(- 7%)	1%

replaced by an expensive source of energy (electricity). It must be emphasized that the trade-off between decreased coke breeze consumption and increased electrical power consumption represents an extremely unfavorable economic balance.

Windbox Gas Recirculation System Capital and Operating Costs

A summary of the projected capital and operating costs for the windbox gas recirculation system is tabulated in Table 3. The capital cost for the windbox gas recirculation system was $5,334,000 when escalated to 1978 market conditions. Depreciation cost for the recirculation system was calculated utilizing this capital cost and an estimated useful life of eighteen years. Utility cost for the operation of the recirculation system was limited to electrical power consumption. It was necessary to prorate the electrical cost for fan operation since only a portion of the power consumed is attributed to recirculation of the gas. It was also necessary to develop a credit for the seven percent reduction in coke breeze consumption which occurred as a result of the optimization of the windbox gas recirculation system. The operating cost for this facility averaged $864,000 per year which is equivalent to $.79 per metric ton of sinter produced.

GRAVEL BED FILTER SYSTEM

Description of Gravel Bed Filter System

Prior to 1957, the gas cleaning applications for gravel bed filtration were limited to batch type operations. In 1957, technology was developed in Germany which permitted the continuous gravel bed filtration of a gas stream. Since that time variations in this design were developed and utilized as air pollution control devices in the cement and lime industries. However, the application of gravel bed filtration technology at a sinter plant did not occur until 1976 when a full scale system was commissioned at Weirton Steel Division.

The gravel bed filter system installed on the No. 2 Sinter Machine at Weirton Steel Division is a special unit specifically designed for sinter plant application. The system consists of a parallel arrangement of 24 filter modules of equal size. The filter modules are assembled into groups of four and are stacked vertically to utilize space more efficiently. There are two such vertically stacked towers, each containing twelve modules (see Figure No. 2).

TABLE NO. 3

TABULATION OF CAPITAL AND OPERATING COSTS
FOR THE
SINTER PLANT WINDBOX GAS RECIRCULATION AND GRAVEL BED FILTER SYSTEMS

	Windbox Gas Recirculation System	Gravel Bed Filter System	Combined Systems
A. Capital (1978 Dollars)	$ 5,334,000	$ 5,101,000	$ 10,435,000
B. Projected Annual Operating Cost (1978 Dollars)			
Repair Labor	70,000	110,000	180,000
Repair Material	96,000	103,000	199,000
Natural Gas	-	150,000	150,000
Electricity	560,000	552,000	1,112,000
Depreciation	296,000	283,000	579,000
Credit for Coke Breeze Reduction	(158,000)	-	(158,000)
TOTAL	864,000	1,198,000	2,062,000
C. Cost per Unit of Sinter Production			
Cost per Metric Ton	$ 0.79	$ 1.10	$ 1.89

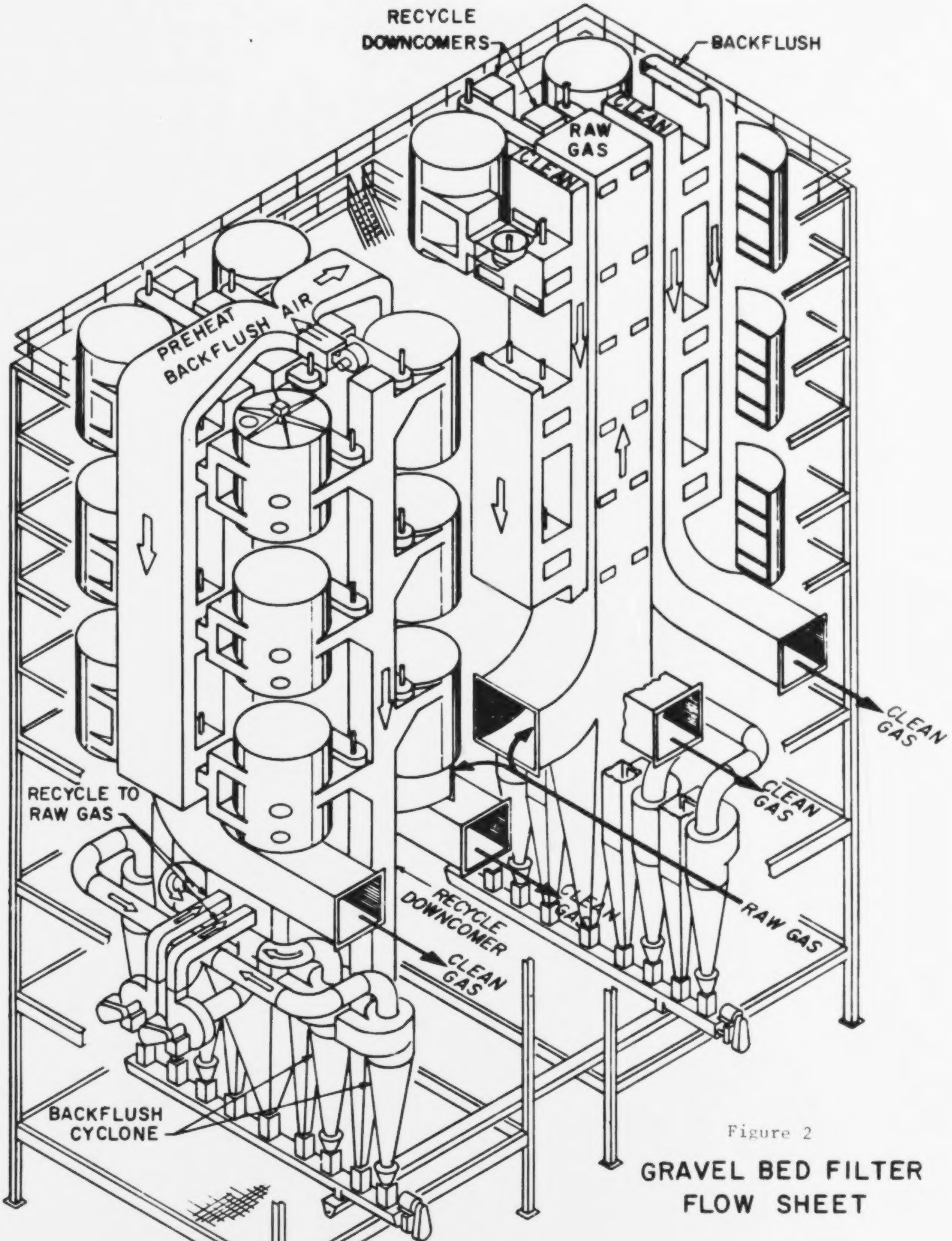

RECYCLE DOWNCOMERS
BACKFLUSH
RAW GAS
CLEAN
CLEAN
PREHEAT BACKFLUSH AIR
CLEAN GAS
CLEAN GAS
RECYCLE TO RAW GAS
CLEAN GAS
RAW GAS
RECYCLE DOWNCOMER
CLEAN GAS
BACKFLUSH CYCLONE

Figure 2

GRAVEL BED FILTER
FLOW SHEET

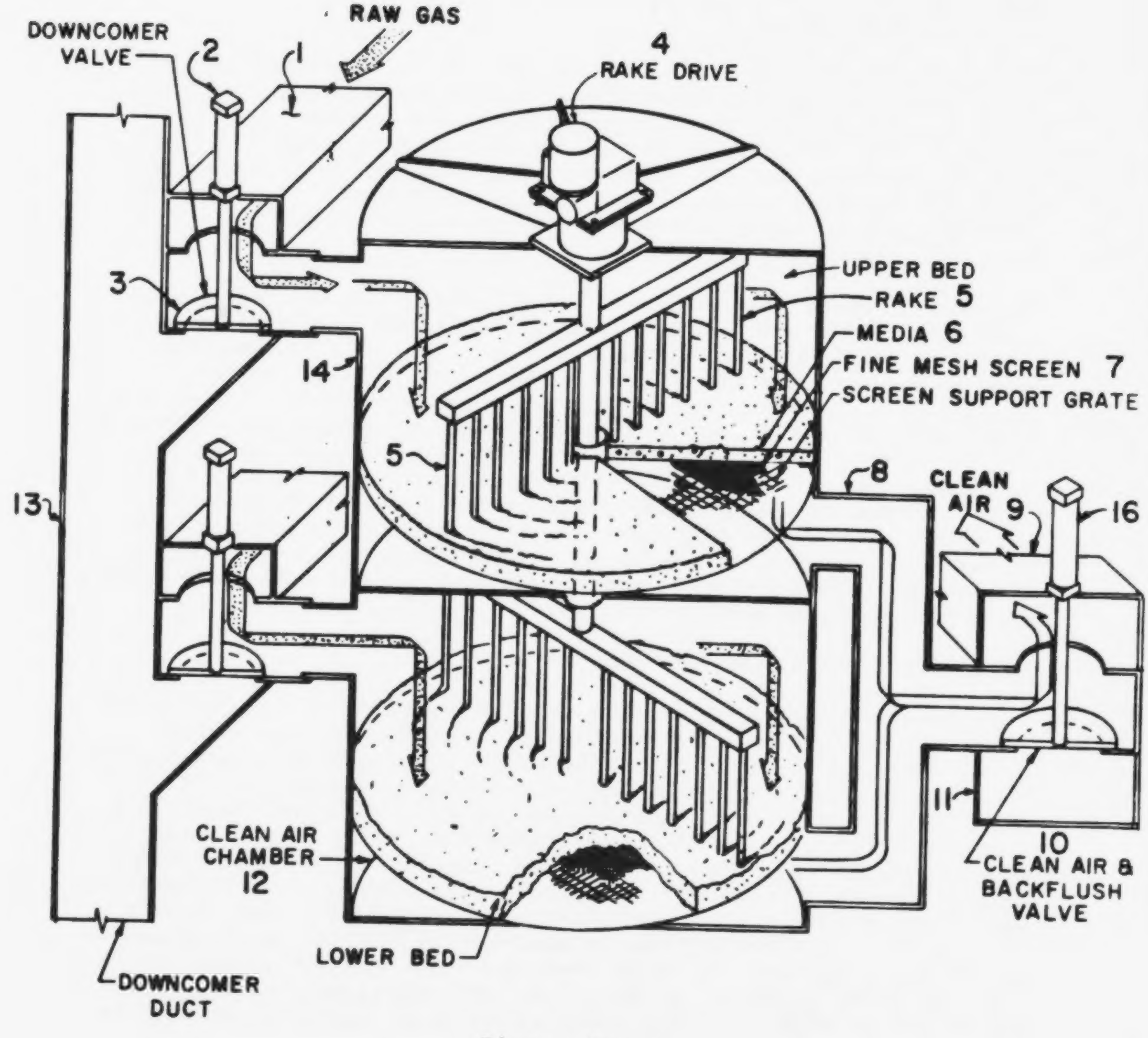
The operation of each filter module is identical; 22 modules are in the forward flow cleaning mode of collecting and filtering sinter dust onto the minute surfaces of the media while two modules (one in each tower) are isolated in a backflushing mode for removal of the collected dust from the filter beds. The system is designed to accept dust laden gas at a flux rate of 0.6 cubic meters per second per square meter of bed area with a flange-to-flange pressure drop of approximately 330 millimeters of water column.

During the forward flow mode (refer to Figure 3) waste gas from the sinter machine enters the filter module through the raw gas duct (1) and passes down through the filter media (6) where the entrained dust is captured. The gas continues through the media support screen (7), and into the clean air duct (9). Note that this flow path is determined by having the downcomer valves (3) and the backflush valve (10) in the down position. The cleaned gas then exits through the gravel bed filter I.D. fan to the stack.

The above "forward flow" or "cleaning mode" continues until the automatic cycle timer in the main control panel calls upon that module to enter the "backflush mode" of operation (refer to Figure 4). At this time, the valve operators (2 and 16) lift the downcomer and backflush valves (3 and 10) to isolate the module from the gravel bed filter I.D. fan. The rake mechanism is activated to agitate the bed, and ambient air, preheated to 150° C., is drawn up through the isolated beds to remove the agglomerated dust. The dust laden gas then passes through a cyclone system and on to the backflush fan which discharges it to the inlet of the gravel bed filter system. The dust collected in the cyclones is recycled back to the sinter machine. After the pre-set backflush time interval has elapsed, the valves are again repositioned to place the module back in the forward or "cleaning mode" position.

Gravel Bed Filter System Operating Problems

Aside from many mechanical problems which occurred in the early stages of debugging, the main obstacle in achieving optimized operation of the gravel bed filter system has been the blinding of the filter media support screens. Shortly after the commissioning of the system, an inspection of the filter modules revealed a severe problem of blinding and adhesion of sinter dust to form a one to ten millimeter cake on the support screens. Since clearance between the rakes and the support screens is maintained at approximately 13 millimeters to avoid screen damage, the media layer next to the screen is not disturbed during the backflush cleaning cycle. Once the screens start to blind, an uneven, high velocity backflushing action occurs and sections of the support screens are left without media cover after the completion of the cycle. This phenomenon is of a very serious nature since it causes short-circuiting of the system and results in reduced particulate removal efficiency.



RAW GAS
DOWNCOMER VALVE
2
1
4
RAKE DRIVE
UPPER BED
RAKE 5
MEDIA 6
FINE MESH SCREEN 7
SCREEN SUPPORT GRATE
3
14
5
8
CLEAN AIR 9
16
13
11
10
CLEAN AIR & BACKFLUSH VALVE
CLEAN AIR CHAMBER 12
LOWER BED
DOWNCOMER DUCT

Figure No. 3

FILTER MODULE FORWARD FLOW MODE

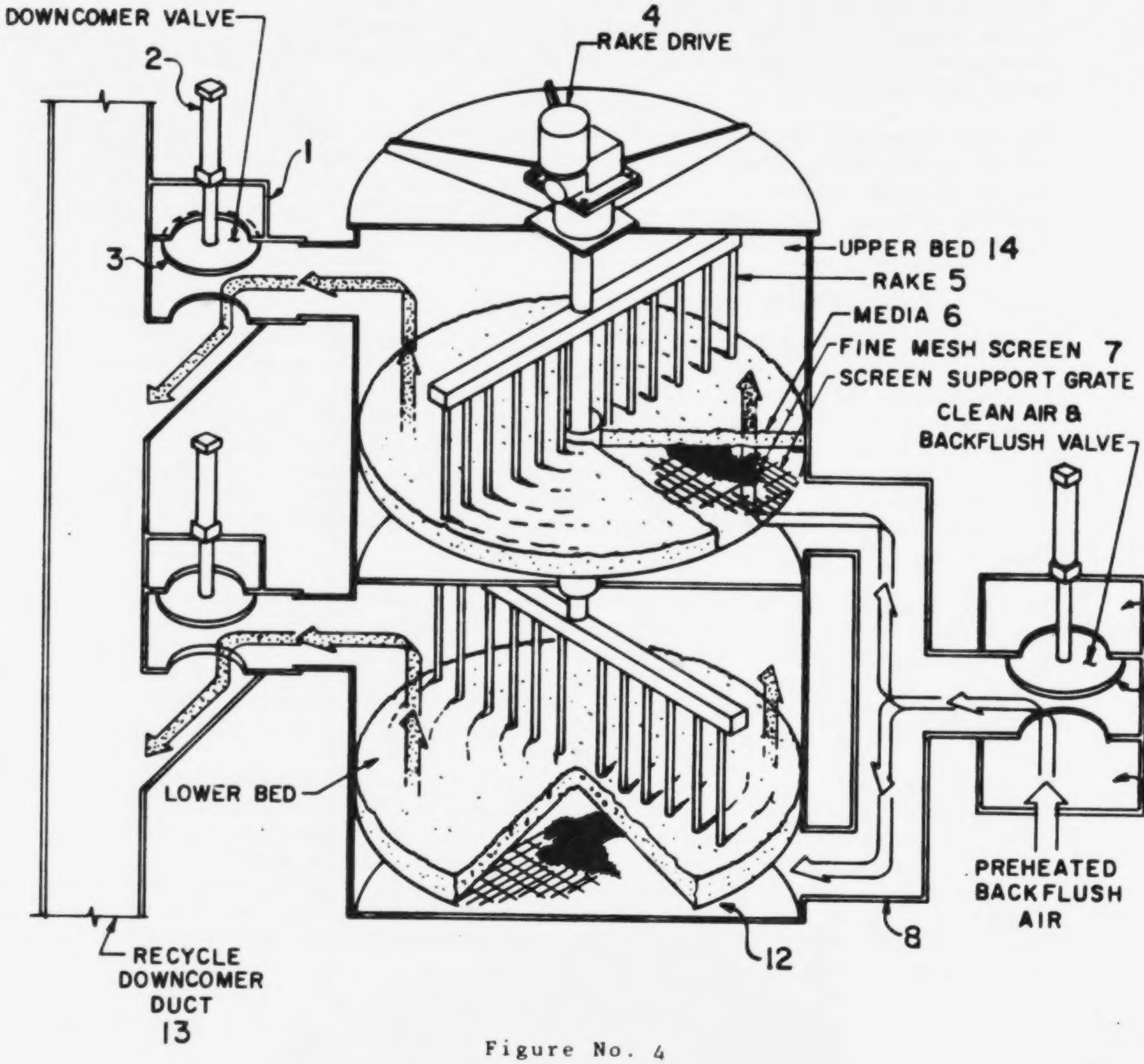

DOWNCOMER VALVE
4
RAKE DRIVE
2
1
3
UPPER BED 14
RAKE 5
MEDIA 6
FINE MESH SCREEN 7
SCREEN SUPPORT GRATE
CLEAN AIR & BACKFLUSH VALVE
9
10
11
LOWER BED
PREHEATED BACKFLUSH AIR
8
12
RECYCLE DOWNCOMER DUCT 13

Figure No. 4

FILTER MODULE
BACKFLUSH MODE

It has been concluded that the principal cause of the screen blinding problem is the condensation of moisture on the screen and the combination of this moisture with the lime-rich sinter dust in the waste gas. Although many programs have been implemented to minimize this problem, its principle cause is inherent in the sintering operation as a result of the frequent start-up and shut-down modes of the machine, and the associated fluctuations in incoming waste gas temperatures to the gravel bed filter system.

The only immediate alternative for obtaining sustained operation of the system is the implementation of a preventative maintenance program in screen cleaning during the scheduled weekly sinter machine down turns. Although costly, this program is being utilized until a more economical alternative is available.

Gravel Bed Filter Environmental Aspects

During the gravel bed filter demonstration period, stack testing was conducted while maintaining an average recycle rate of twenty-five percent in the windbox gas recirculation system. The results of this testing indicated that the average inlet particulate concentration to the gravel bed filter system was 1565 mg/Nm^3. Stack gas testing simultaneously taken at the outlet of the gravel bed filter system indicated an average particulate concentration of 156 mg/Nm^3. The average particulate removal efficiency during this mode of operation was ninety percent with a range from 81 percent to 95 percent.

The detrimental effects of the screen blinding problem on the operating reliability and performance of the gravel bed filter system cannot be over-emphasized. Under optimized conditions, the gravel bed filter system has demonstrated the capability of producing an effluent concentration of less than 70 mg/Nm^3 of particulate. During periods of malfunction with partially blinded screens, the effluent concentration is more than tripled.

Testing indicated that gravel bed filtration reduced condensable hydrocarbon emissions by approximately twenty-eight percent. It is presumed that this reduction occurred due to condensation and deposition in the system at temperatures below 120^{o} C. The benefit of this condition is questionable since it could be contributing to the screen blinding problem. Again, it must be emphasized that due to the uncertainities involved in the method of condensable hydrocarbon determinations, data generated for this parameter should be viewed accordingly.

Gravel Bed Filter Energy Consumption

During the demonstration period the flux rate through the gravel bed filter system was well below the design due to the limitations of the induced draft fan. This fan limited the filtration process to forty percent of the total sinter machine windbox gas volume. Recently revisions to the gravel bed filter system were implemented to permit the treatment of sixty percent of the total sinter machine windbox gas volume. With these revisions, the total electrical requirements, including auxiliary motors for backflush fans and hydraulic pumps increased to 3200 horsepower. In addition, natural gas is utilized at a rate of 3.5 cubic meters per minute to preheat the backflush air from ambient temperature to 150° C.

The Sinter Plant energy consumption at that time increased 46 joules/m.t. or 32 percent for electricity and 47 joules/m.t. or 21 percent for coke oven/natural gas (see Table 2). The total Sinter Plant energy consumption increased 93 joules/m.t. or four percent from 2441 joules/m.t. to 2534 joules/m.t. of sinter production.

Gravel Bed Filter Capital and Operating Costs

A summary of the capital and operating cost for the gravel bed filter system is tabulated in Table 3.

The capital cost for the revised gravel bed filter system is $5,101,000 when equated to 1978 market conditions. Depreciation cost for the gravel bed filter system was calculated utilizing this capital cost and an estimated useful life of eighteen years. Costs for electrical power and natural gas consumption were derived utilizing design data. The projected operating costs for the system is $1,198,000 per year which is equivalent to $1.10 per metric ton of sinter produced.

Combined Windbox Gas Recirculation and Gravel Bed Filter System

An analyses of the environmental capabilities of the combined windbox gas recirculation and gravel bed filter systems cannot be accurately documented until the systems are totally optimized. As stated previously the Company is aggressively pursuing programs to reduce the total effluent volume from the sinter machine and improve environmental performance.

Table 2 indicates the change in Sinter Plant energy comsumption due to the combined windbox gas recirculation and gravel bed filter systems. This projection indicates an increase in electrical power consumption of 86 percent of 123 joules/m.t. of sinter production, an increase in coke oven/natural gas consumption of 21 percent of 47 joules/m.t., and a decrease in coke breeze consumption of 7 percent or 146 joules/m.t. of sinter production. The projection also indicates that the total energy consumption has increased one percent or 24 joules/m.t. of sinter. Again, it must be emphasized that the trade-off between the decreased coke breeze consumption and the increased electrical power consumption presents an extremely unfavorable economic balance.

The total capital cost for the combined system is $10,435,000 based on 1978 market conditions. The projected operating cost for the combined systems is $2,062,000 per year or $1.89 per metric ton of sinter produced. The capital and operating costs will escalate depending upon the future expenditures necessary to optimize the system.

It must be emphasized that this windbox gas recirculation and gravel bed filter demonstration is a full-scale research and development program which has not yet reached a conclusion. At this point in time, an overall evaluation of these facilities indicates both strong advantages and serious disadvantages. However, the relative merits of these technologies cannot be established until the optimization of the facilities is achieved. For this reason, recommendations concerning the acceptability of these technologies are reserved until a later date.

RTI1547/Conference Paper OCTOBER, 1979

REVIEW OF FOREIGN AIR POLLUTION CONTROL TECHNOLOGY FOR BOF FUGITIVE EMISSIONS

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ABSTRACT

This paper reviews BOF fugitive emission control technology in use in foreign steel plants. The discussion presented is based on literature review and visits to twelve iron and steel plants in Western Europe and Japan. Basically two categories of fugitive emissions control technology have been seen during the foreign plant visits. One category relies strictly on local hooding; the other category combines local hooding and partial building evacuation. Both are described in general terms in this paper. Then one plant, one of the best visited in Western Europe that relies strictly on local hooding is described in more detail.

1.0 INTRODUCTION

This paper reviews BOF fugitive emission control technology in use in foreign steel plants. The discussion presented is based on literature review and visits to twelve iron and steel plants in Western Europe and Japan. This survey has been performed to provide the basis for comparison of foreign technology with that in use in the United States, and where the foreign technology is superior, show how it may be applied to domestic steelmaking practice. Control of fugitive particulate emissions from BOF steelmaking and desulfurization of iron outside the blast furnace are being emphasized in this study.

Basically two categories of fugitive emissions control technology have been seen during the foreign plant visits. One category relies strictly on local hooding; the other category combines local hooding and partial building evacuation. Both are described in general terms in this paper. One plant, in Western Europe that relies strictly on local hooding is described in more detail.

This paper also serves as a status report on the EPA project acknowledged in Section 4.0. A further goal of this study is to conduct tests in two foreign plants to document the capture and control capability of technology that is determined to be superior. The applicability to domestic steelmaking practice will be determined on the basis of an engineering study using data obtained during the foreign plant visits.

Additional reports will be issued on these subjects.

2.0 GENERAL DESCRIPTION OF BOF FUGITIVE EMISSION CONTROL TECHNOLOGY

The fugitive or secondary emission sources of interest in this study are those from furnace charging and tapping, hot metal transfer, desulfurization of iron in torpedo cars or ladles, deslagging of torpedo cars or ladles, deskulling of ladles, and furnace puffing in the case of suppressed combustion primary fume control systems. At the time this project was begun there were virtually no plants in the United States that had attempted to capture emissions from all or almost all of the above sources. A few plants had installed control systems for capturing furnace charging, puffing, and tapping emissions. Others had installed only hot metal transfer emission control systems. Since 1977, the number of U.S. plants with some furnace charging control has more than doubled to nine. However, only three plants have installed more complete secondary emission control systems, i.e., including such things as hot metal transfer, deslagging and deskulling, and desulfurization. Two of these plants retrofitted their secondary emission control systems; the third was built as part of a new plant.

Only one plant in the United States is known to have attempted secondary emission control by combining local hooding and partial building evacuation. One plant combines local hoods and canopy hoods above the charging aisle, and the remainder only use some form of local hooding.

The foreign plants selected for visits were chosen on the basis of reports in the technical literature, vendor experience lists, trip reports from previous EPA foreign plant visits, and discussions with knowledgeable visitors from foreign countries. The five plants selected in Western Europe were as follows:

British Steel - Lackenby Works
Krupp - Rheinhausen Works
Hoogovens - Ijmuiden, Netherlands

Swedish Steel - Oxelosunds, Sweden
Italsider - Taranto Works

The above plants were visited in March of 1979. Seven Japanese steel plants were visited in September and October of 1979. They were as follows:

Nippon Steel - Oita Works
Nippon Steel - Yawata Works
Sumitomo Metal Industries - Kashima Works
Kawasaki Steel - Chiba Works
Kawasaki Steel - Mizushima Works
Kobe Steel - Kakogawa Works
Nippon Kokan - Ohgishima Works

Table 1 provides a general description of the emission control technology in each plant. The two basic approaches used for secondary emission control are local hooding and local hooding plus partial building evacuation. Figure 1 shows a schematic flow diagram of a local hooding secondary system connected to a fabric filter. Figure 2 shows a plant arrangement in which a roof wet ESP is used for partial building evacuation.

Only one of the plants, however, chose to combine local hooding and partial building evacuation in the initial construction of the plant. The Chiba Works of Kawasaki did include partial building evacuation through a roof-mounted wet ESP in the construction of their Q-BOP. All the other plants have retrofit the partial building evacuation systems, presumably due to ineffectiveness of their local hoods alone and changing environmental requirements.

Two plants were identified as having some secondary emission capture for deslagging and dekishing of torpedo cars, and hot metal transfer in separate, small, enclosed buildings. The basic design principles involved for these, however, are closer to local hooding than building evacuation.

As is evident from Table 1, the control device of choice is the fabric filter with a few exceptions. One of the exceptions arises through the use of one Baumco system design that processes charging emission waste gas through the primary fume scrubber. This system is best adapted to shops with larger

TABLE 1. FOREIGN SECONDARY EMISSION CONTROLS

Company/Plant	Emission Control Technology Secondary Furnace Emissions	Emission Control Technology Hot Metal Transfer, Desulfurization, Deslagging, Etc.
British Steel, Lackenby	Local Hoods + Canopy hoods - Scrubbers	Local Hoods - Scrubbers
Krupp, Rheinhausen	Local Hoods - Scrubbers	Local Hoods - Scrubber
Hoogovens, Ijmuiden Plant No. 2	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter & Scrubber
Swedish Steel, Oxelosund	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter
Italsider, Taranto Plant No. 2	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter
Nippon Steel, Oita	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter, Enclosed Building Evacuation - ESP
Nippon Steel, Yawata Plant No. 3	Local Hoods - Fabric Filter	Local Hoods + Enclosed Building Evacuation - Fabric Filter
Sumitomo, Kashima Plant No. 2	Local Hoods + Partial Building Evacuation - Fabric Filter	Local Hoods - Fabric Filter
Kawasaki, Chiba Plant No. 3	Local Hoods - Fabric Filter Partial Building Evacuation - Roof Wet ESP	Local Hoods - Fabric Filter
Kawasaki, Mizushima Plant No. 1	Same as Chiba	Local Hoods - Fabric Filter
Plant No. 2	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter

TABLE 1. (Continued)

Company/Plant	Emission Control Technology	
	Secondary Furnace Emissions	Hot Metal Transfer, Desulfurization, Deslagging, Etc.
Kobe, Kakogawa	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter
Nippon Kokan, Ohgishima	Local Hoods - Fabric Filter	Local Hoods - Fabric Filter

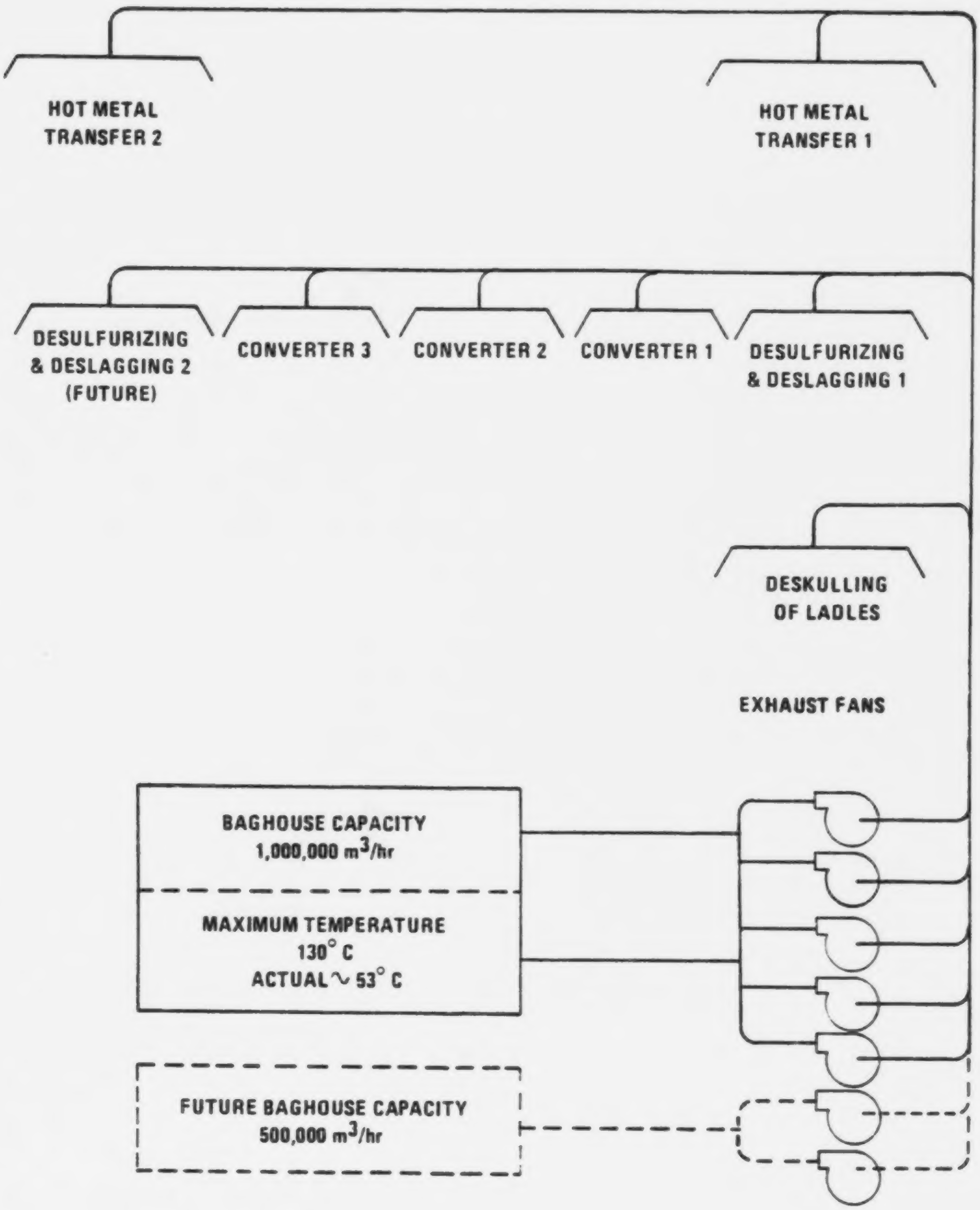
HOT METAL TRANSFER 2
HOT METAL TRANSFER 1
DESULFURIZING & DESLAGGING 2 (FUTURE)
CONVERTER 3
CONVERTER 2
CONVERTER 1
DESULFURIZING & DESLAGGING 1
DESKULLING OF LADLES
EXHAUST FANS
BAGHOUSE CAPACITY 1,000,000 m3/hr
MAXIMUM TEMPERATURE 130° C
ACTUAL ∿ 53° C
FUTURE BAGHOUSE CAPACITY 500,000 m3/hr

Figure 1. Italsider-Taranto basic oxygen steelmaking secondary ventilation system.

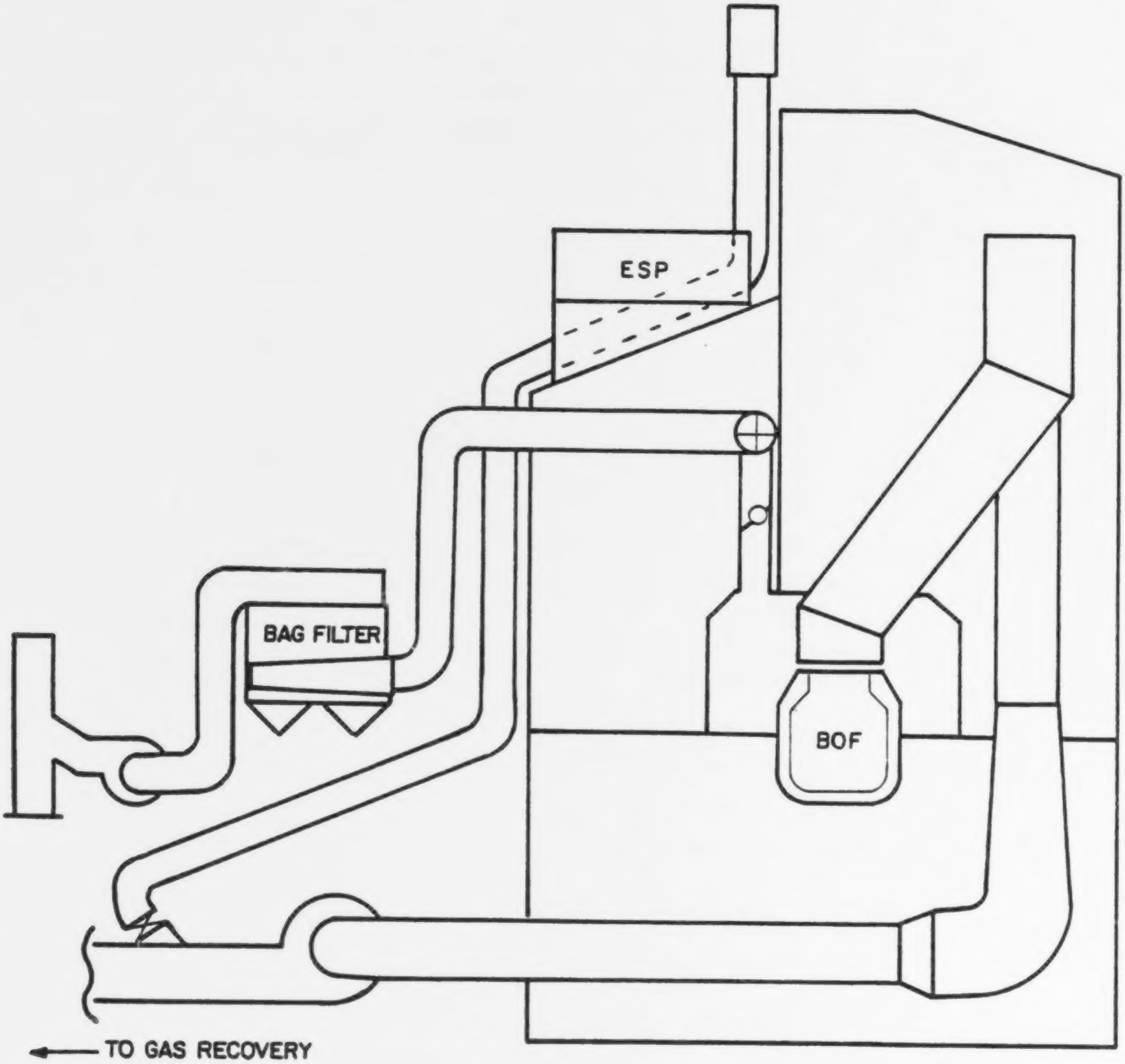
ESP
BAG FILTER
BOF
TO GAS RECOVERY

Figure 2. Plant arrangement with partial building evacuation.

vessels where the primary fume control systems have larger design gas flows needed for control of charging emissions. While the obvious advantage of this arrangement is the reduction of air flow needs in a separate secondary emissions control system, the disadvantage may be poor control of charging emissions depending on scrap quality and the limited gas flow available from the primary system. When charging emissions are treated as part of a larger secondary emission control system, it is possible to divert gas flow from other secondary operations long enough to ensure good control of heavy fuming charges.

Another exception to the fabric filter choice is the roof-mounted wet ESPs in use in Japan for partial building evacuation. The particular design in use in the plants visited has no air moving equipment attached to it. Air movement through them is generated strictly by thermal drafts induced by the shop heat. The principal advantage of such a system is, therefore, reduced energy consumption because fan power to move the air through a fabric filter is not necessary. There are other factors that must be weighed against this advantage such as reinforcement of building structure to take the roof load, and wastewater treatment. The wastewater treatment consequence is probably not significant since most of the recently constructed BOFs use scrubbers for primary fume control and will have wastewater treatment facilities.

The choice between furnace emission control strictly by local hooding or in combination with partial building evacuation is expected to vary with the particular site conditions. For instance, Q-BOP charging may present more difficulty in achieving good charging fume control by local hoods because of the necessity for blowing gas through the tuyeres when the vessel is turned down. In this case partial building evacuation might be a better choice. Heavy fuming produced by dirty scrap might also provide the incentive for partial building evacuation. In retrofitting an additional furnace vessel to an existing shop with inadequate space for good local hooding and ducting, partial building evacuation could supplement a less efficient local hood system.

The advantage, in general, of using local hooding instead of partial building evacuation is that air volumes treated are smaller and hence energy consumption is lower. The building evacuation system without an air mover might be an exception. The engineering study to follow in this project is expected to provide insight into this matter.

Performance Observations

In all of the plants visited, performance observations were made on the secondary emission control systems. The principal effort was to visually evaluate the capture capabilities of the various local hoods. Where partial building evacuation was used, building emissions were observed. Since there is no standard method for visual determination of capture, the performance estimates are subjective. In addition, the ultimate determination of which systems are the best must also consider differences in process conditions between plants i.e., scrap quality and the relative proportion of scrap versus hot metal. The overall evaluations are not yet complete, so specific observations are not reported in this paper. What can be said is that the best performing technology observed for each of the secondary sources provided virtually complete capture of the fumes with capture efficiencies estimated in the range of 90 to 100 percent. As pointed out above, these estimates must yet be combined with process conditions to relate the system performance to typical United States plant conditions.

On the basis of our subjective performance estimates and review of the system design and plant operations, our preliminary evaluation of the Western Europe plant visits suggests that the Italsider - Taranto Works had the best overall secondary emission control systems. Because of similarities in design and performance between several Japanese plants visited and the Taranto Works, the latter was selected for a more detailed description in this paper.

Specific Plant Description

The Taranto Works secondary emission control system depends entirely on local hoods for emissions capture. Figure 1 shows a flow diagram for the secondary ventilation system. As shown, there are eight collection points, five exhaust fans (one spare) and a dual-section, pressurized baghouse having a total of 10 compartments. Each compartment has 144 bags, which are 300 mm diameter by 9120 mm long, yielding a net total cloth area of 12,400 m^2. The cloth is "Terylene", a synthetic fabric suitable for a service temperature of 130°C. Upon startup of the system, Taranto operated one baghouse with five compartments, later adding the second five compartments. Initially there were three fans, but two more were added. They are now considering the addition of five more compartments as well as additional fans in order to raise the system capacity from 1,000,000 m^3/hr to 1,500,000 m^3/hr. Additional pickup points would then be added such as ladle repair stations.

Table 2 shows the designed flow and temperature condition at each of the hoods. In considering the table, it should be noted that desulfurizing and deslagging Station 1 is out of service because it provides for pneumatic injection of carbide which is no longer in use. The deskulling station is also out of service because the dust from that operation was too heavy and built up in the ductwork, thereby putting the hood out of commission. A comparison of the total system volume presented in Table 2 with the baghouse capacity as shown in Figure 1, indicates that time-sharing of the suction capacity among the various operations is practiced. It also indicates that gas cooling takes place in the suction duct between the hoods and the baghouse. In normal operation, four of the existing five fans are operating and one is in standby condition. The bags are cleaned by reverse air flow which was originally provided by a small auxiliary blower.

Figure 3 shows a general arrangement of the doghouse and the main suction (charging) hood at the converter. Not shown are two hinged doors of heavy plate at the front of the furnace, each about four meters high. The back end of the doghouse is closed by means of hinged plate doors, however, the front is open except for partial closure by a pipe curtain at the top which serves to direct the fumes into the opening of the hood. At the front of the doghouse, there is the main hood with three opening as shown in Figure 3. At the rear, there is a smaller auxiliary hood to collect a portion of the emissions from tapping the furnace. The other portion is directed to the front hood by means of the sloping sections in the roof and sides of the doghouse at the rear.

The sketch of Figure 3 was made by visual observation during the visit without measurements. It is, therefore, to be taken as a rough approximation of the actual arrangements. The upper hood face (charging hood) was estimated to be 7.6 meters wide. The upper face opening appeared to be about 60 cm wider on each side than the outside diameter of the hood skirt.

Figure 4 shows a drawing of the hood at the hot metal transfer station. As shown, the top of the furnace ladle fits into close configuration with the bottom of the hood which, therefore, provides a continuation to the exhaust system. The ventilating slot is approximately 1½ to 2 meters wide for admis-

TABLE 2. SECONDARY VENTILATION SYSTEM SUCTION VOLUMES

Hood Description	Flow, m^3/min	Temperature, °C
1. Converter hood		
a. Open - Hot metal charging	10,000	480
b. Closed - Puffing during blow	2,500	60
2. Deslagging	3,000	200
3. Desulfurization	1,800	130
4. Hot metal transfer	3,000	130
5. Deskulling	1,500	150
TOTAL	21,800 = 1,300,000 m^3/hr	294

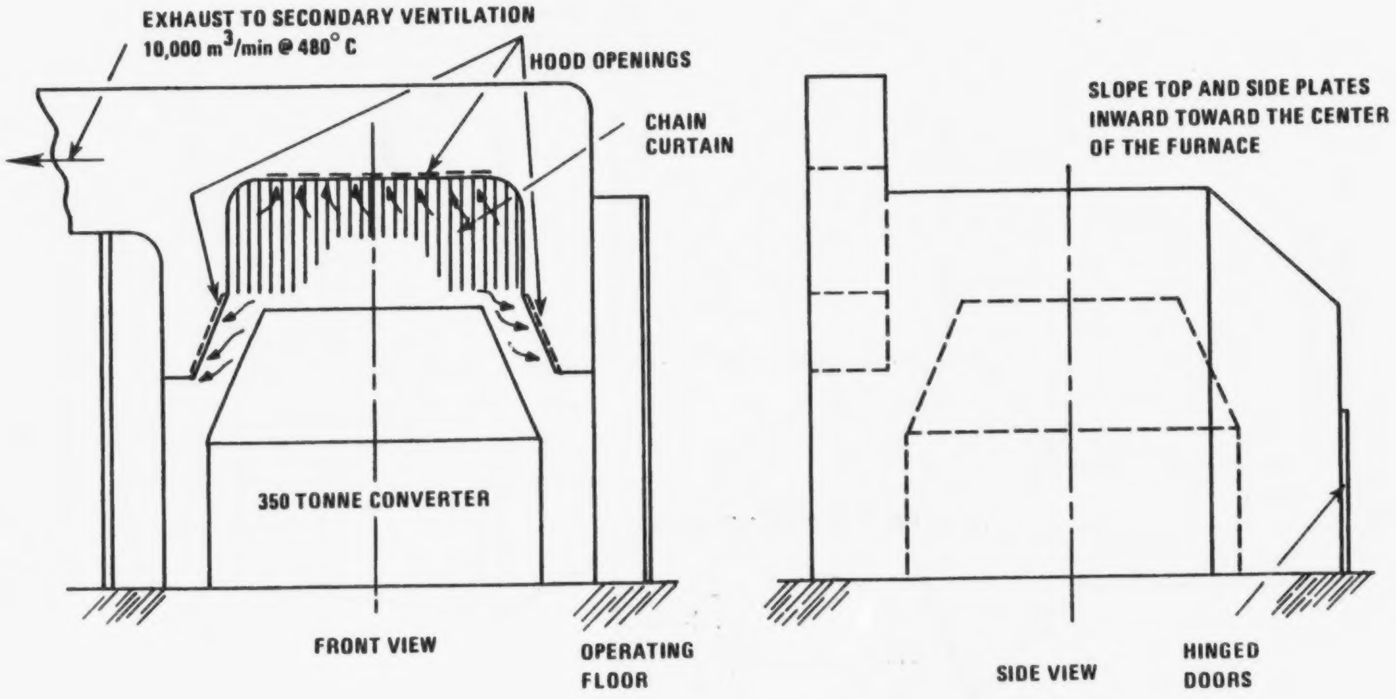
EXHAUST TO SECONDARY VENTILATION
10,000 m^3/min @ 480° C
HOOD OPENINGS
CHAIN CURTAIN
350 TONNE CONVERTER
FRONT VIEW
OPERATING FLOOR
SLOPE TOP AND SIDE PLATES INWARD TOWARD THE CENTER OF THE FURNACE
SIDE VIEW
HINGED DOORS

Figure 3. Italsider-Taranto basic oxygen steelmaking --doghouse arrangement.

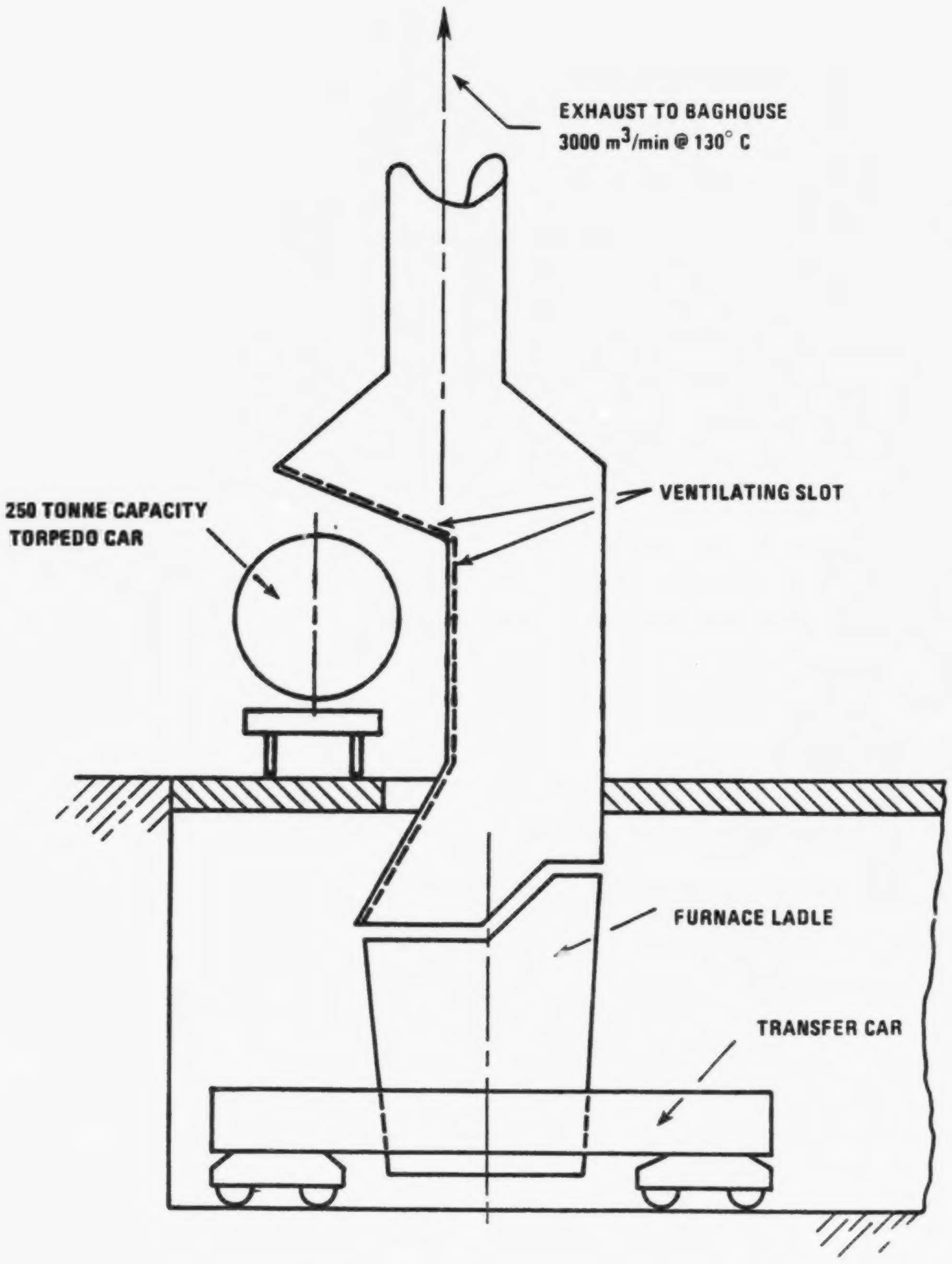
EXHAUST TO BAGHOUSE
3000 m3/min @ 130° C
VENTILATING SLOT
250 TONNE CAPACITY
TORPEDO CAR
FURNACE LADLE
TRANSFER CAR

Figure 4. Italsider-Taranto basic oxygen steelmaking --hot metal transfer.

sion of the molten iron to the furnace ladle and for fume capture from the torpedo car. The hood is arranged so that it extends well beyond the center line of the torpedo car. The entire hot metal transfer station is partially enclosed by a separate building which is external to the BOF shop. The building is open on both ends to permit movement of torpedo cars through it by rail.

In the desulfurization building, adjacent to the BOF shop, there are two fume collection hoods. One hood serves the deslagging station; the other hood serves the desulfurization staton. Both hoods are mounted above the ladle position, closely fitted to it, and of essentially the same diameter as the opening in the ladle. This is made possible by the fact that the ladle is mounted on a transfer car that moves it into place below the hoods. Clearance from the top of the ladle to the underside of the circular hood face in the desulfurization station is approximately 30 cm. The close-fitting deslagging hood or enclosure is actually rectangular (in spite of previous reference to diameter) and is open on the side where the slag rake is mounted. The fourth side of the deslagging hood is effectively provided by the wall of the building.

A highly desirable feature of the secondary ventilation system is the methods which are used for controlling the valves to admit suction at the various hoods. The desirability of the system lies in two factors. One is the provision for a single control valve at each converter which minimizes the number of operating conditions and control variables. The other is the simplified concept of the control scheme as will be described in the following paragraphs.

At each converter hood, there is one valve that is used in two positions, fully opened or closed. When it is opened it will pass 10,000 m^3/min to accommodate the capture requirements during hot metal charge. When the valve is closed, it fits loosely in the duct and permits the passage of 2,500 m^3/min to capture the fumes which result from puffing during the blow, from tapping and slagging the furnace.

Each furnace pulpit has a panel in which there are manually operated controls for the valves as well as indicating lights to show the position, either open or closed, of the valves on each of the three converters. The controls at any vessel are arranged so that the operator can close any of the three valves, but only open the valve pertaining to his vessel. This simple, but effective, concept permits the operator to obtain maximize suction when his vessel is being charged with molten iron and permits him to minimize suction demands from the other two vessels at that time. The concept is made possible by the fact that only one vessel may be charged with molten iron at any single instant.

At the hot metal transfer station, the opening of the valves to the suction hood is interlocked with the control rotating the torpedo vessel in order to pour the iron. Shutoff is controlled by a timer that closes the valve after seven minutes of operation.

At the desulfurizing station, the opening of the valve to the suction hood is initiated automatically upon the descent of the stirring device into the ladle. When the stirring device is withdrawn, the valve is closed. At this location, there is also a small exhaust take-off to the carbide handling system.

At the deslagging station, each movement of the rake opens and closes the valve for the suction hood. When the rake travels to its extreme position an electrical interlock opens the valve. When the rake returns to the retract position, the valve closes. This means that during the raking of the slag, the valve opens and closes approximately 15 times a minute. When the rake is in the parked position at the shutdown of the deslagging operation, the valve is automatically closed and remains so.

At Taranto, the special features of particular note were associated with the secondary fume control system. Of particular interest was the simple method of bringing each suction hood on line when needed and insuring that it was closed when not in operation. The other feature of particular note was the side-by-side location of desulfurization and deslagging for the molten iron. This was a very efficient arrangement from the standpoint of operations and, because the ladle was transported by a transfer car which had a tilting feature, it was possible to design a very satisfactory fume capture system.

3.0 CONCLUSIONS

The two categories of systems for BOF secondary emissions control seen in the foreign plants were based on

1) local hooding only, and
2) local hooding plus partial building evacuation.

While the partial building evacuation systems for furnace emissions were not in the majority, there are several situations in which such installations may offer advantages over the use of only local hooding. In particular, the use of roof-mounted ESPs with no fans attached, and therefore no air moving--pressure drop energy costs, may be a cost effective alternative to complete reliance on local hooding connected to fabric filters.

The particulate collection device in most common use for secondary emission control systems is the fabric filter. Scrubbers and ESPs are used in only a few plants of the plants visited.

In respect to performance or capture capability of the local hooding applications, the best systems observed captured virtually all of the secondary emissions. The method of estimating capture efficiency was subjective, but best performance was in the range of 90 to 100 percent capture.

The Italsider - Taranto Works secondary emission control system was similar in design and performance to several seen during the Japanese plant visits. A preliminary evaluation suggests the Taranto Works secondary emission control system was the best of the plants visited in Western Europe.

4.0 ACKNOWLEDGEMENT

The background data supporting the information contained in this paper was obtained as part of the work effort under Contract 68-02-2651 between Research Triangle Institute and the U.S. Environmental Protection Agency. The project is funded by the Ferrous Metallurgical Branch of the Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina. Mr. Norman Plaks is the EPA Project Officer.

5.0 REFERENCES

1. Drabkin, M. and Helfand, R., "A Review of Standards of Performance for New Stationary Sources-Iron and Steel Plants/Basic Oxygen Furnaces," Mitre Corporation for U.S. Environmental Protection Agency, EPA-450/3-78-116, November 1978.

2. Steiner, J., "Trip Report - Presurvey of BOF Shop Republic Steel, Cleveland, Ohio," Accurex Corporation for U.S. Environmental Protection Agency, Division of Stationary Source Enforcement, July 27, 1978.

3. Jablin, R. and Coy, D., "Trip Report - Italsider Steel Company, Taranto, Plant," Research Triangle Institute, March 26, 1979.

FUGITIVE PARTICULATE EMISSION FACTORS FOR BOP OPERATIONS

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ABSTRACT

Extensive testing was conducted at two steel mills to measure the amount of fugitive particulate emissions generated during BOP hot metal addition and tapping operations. Tests were conducted on a new Q-BOP installation equipped with a doghouse and a single secondary collection hood; tests were also conducted on an existing BOP installation retrofitted with a doghouse and multiple secondary collection hoods. Particulate emission data was correlated with several process parameters, vessel operating characteristics and visual observations inside and outside each shop. Particulate emission factors for hot metal addition to the Q-BOP and the BOP averaged 0.6 lb per ton (particulate emitted per ton of hot metal added to the vessel) with a range of 0.2 to 1.2 lb per ton and 0.25 lb per ton with a range of 0.16 to 0.32 lb per ton, respectively. For tapping operations, the particulate emission factors for the Q-BOP and the BOP were 0.92 lb per ton (particulate emitted per ton of steel tapped) with a range of 0.15 to 2.28 lb per ton and 0.16 lb per ton with a range of 0.05 to 0.24 lb per ton, respectively.

FUGITIVE PARTICULATE EMISSION FACTORS FOR BOP OPERATIONS

INTRODUCTION

The Energy and Environmental Division of Acurex Corporation undertook a series of tests for EPA Region 5 at two steel mills to determine fugitive particulate emission factors for hot metal addition and tapping. Tests were conducted on a Q-BOP operation at Republic Steel's Chicago Works in 1978 and on a BOP operation at Republic Steel's Cleveland Works in 1979. A concise description of each facility, test program and results is presented below.

Q-BOP TEST PROGRAM

Facility Operation

Republic Steel Corporation operates a two-vessel Q-BOP shop (225 tons steel/heat) at its Chicago Works. Each vessel is equipped with a doghouse enclosure, a secondary collection hood (charge side only) and removal system design by Pennsylvania Engineering Corporation. Figure 1 illustrates hot metal being charged to the vessel with the doghouse doors open and the secondary collection hood in operation.

At the start of a heat the doghouse doors were opened and the vessel was rotated toward the charge side. Suction on the secondary collection hood (330,887 dscfm) was automatically initiated as soon as the vessel was displaced more than 20° from the vertical position. Suction on the primary collection hood (above the vessel) was reduced to approximately 10 percent of full capacity. Figure 2 illustrates the dampers and ductwork for the primary and secondary collection and gas cleaning systems necessary to accomplish this flow distribution. Scrap was added to the vessel via the charge machine. Hot metal was then added to the vessel using a hot metal ladle and overhead crane. Two ladle additions were necessary to introduce the proper weight of hot metal for a heat. While the vessel was accepting a charge of scrap or hot metal, N_2 was blown through the tuyeres in the bottom of the vessel to prevent them from getting plugged. The N_2 blowrate was higher during hot metal addition than during scrap addition. During the test program the average hot metal addition time (2 ladles) was 2.9 min and the average amount of hot metal charged was 203.7 tons (2 ladles). Fumes emitted during scrap and hot metal addition were captured by the secondary collection hood on the charge side of the vessel and were ducted to the venturi scrubbers for removal. Emissions escaping collection by the secondary collection hood drifted upward and entered the atmosphere via the shop roof monitor.

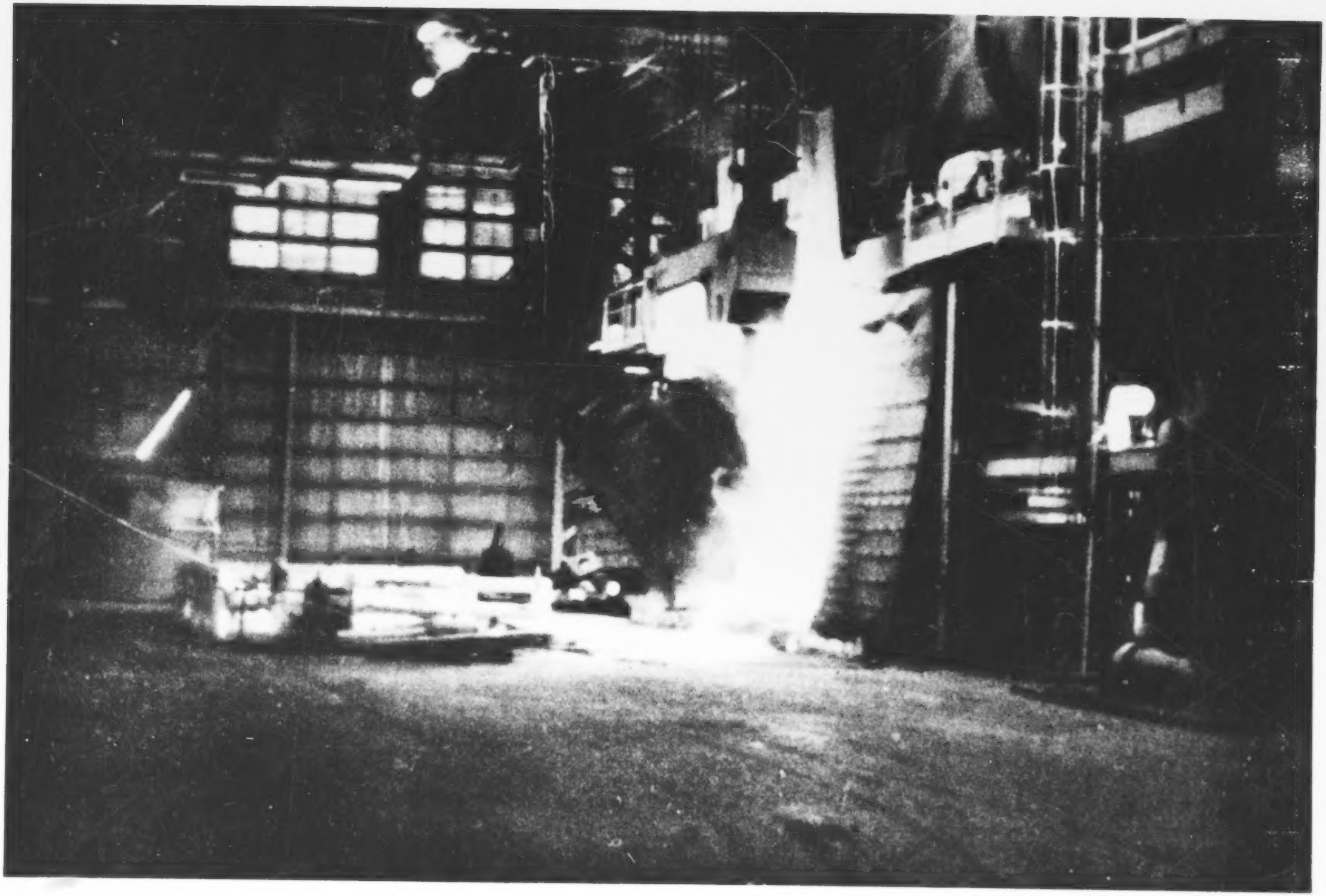

Figure 1. Hot metal addition to Q-BOP at Republic Steel, Chicago.

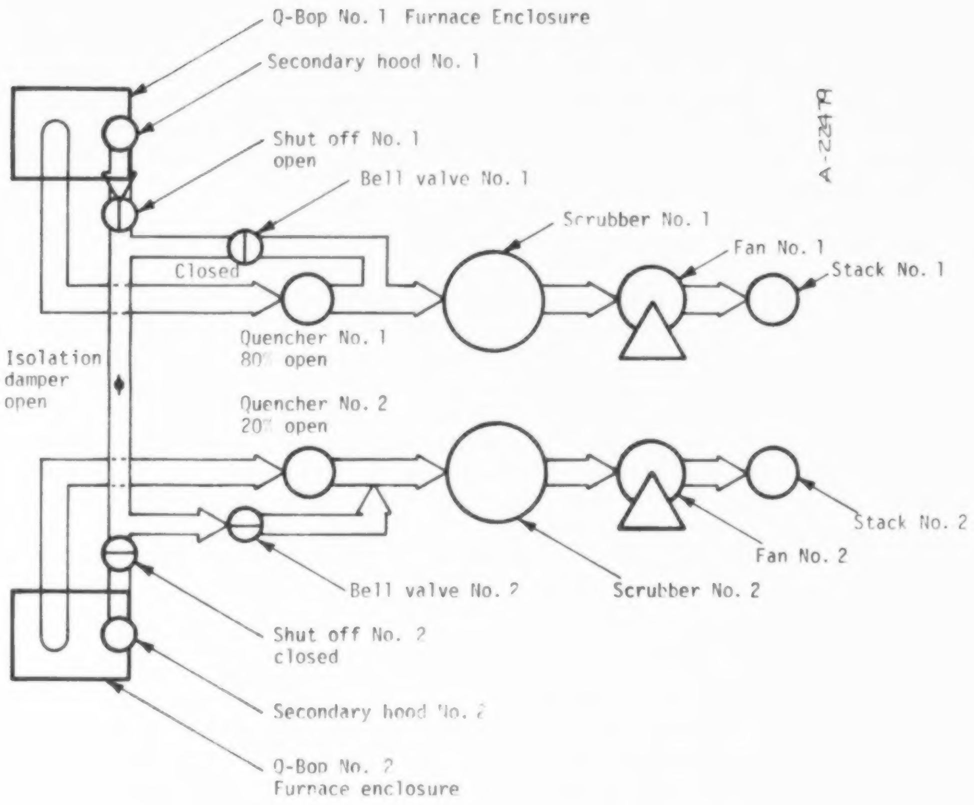
Q-Bop No. 1 Furnace Enclosure
Secondary hood No. 1
A-22479
Shut off No. 1
open
Bell valve No. 1
Scrubber No. 1
Fan No. 1
Stack No. 1
Closed
Quencher No. 1
80% open
Isolation
damper
open
Quencher No. 2
20% open
Stack No. 2
Fan No. 2
Bell valve No. 2
Scrubber No. 2
Shut off No. 2
closed
Secondary hood No. 2
Q-Bop No. 2
Furnace enclosure

Figure 2. Flowchart for primary and secondary collection and gas cleaning system for Republic Steel Q-BOP shop.

After charging was complete, the vessel was turned up to the vertical position in preparation for O_2 blow. The doghouse doors were closed and the secondary collection hood was shut off with the primary collection hood in operation. After completion of O_2 blow, the vessel was rotated to the tap position. Again, as the vessel moved 20° past the vertical position, the secondary collection hood went into operation. Fugitive particulate emissions, generated as the steel and additives were poured into the teeming ladle, were captured and sent to the venturi scrubbers for removal.

Test Location

The particulate mass and size measurements were made in the ductwork connecting the secondary collection hood to the pollution control equipment as illustrated in Figure 3. The single sampling port (for horizontal traverse of duct) was 1.5 diameters downstream of a bend in the duct and only 0.5 diameters upstream of the downcomer leading to the quencher. No traversing was done in the vertical direction because of the overhead crane clearance requirements. This test location was used for both the hot metal addition and the tapping tests.

Test Equipment

Since the hot metal addition and tapping portions of the BOP cycle were of relatively short duration, high volume (~ 5 scfm) particulate mass and size sampling trains were used to collect large enough samples for subsequent analysis. The particulate mass tests were conducted using an EPA Method 5 sampling system as illustrated in Figure 4; the particle size measurements were made using a Source Assessment Stack Sampler (SASS) as shown in Figure 5. The Method 5 train was equipped with a 3μ cyclone to remove the large flakes of kish and to prevent tearing of the glass fiber filter. The particle size train consisted of 10.5μ, 3.6μ, 1.55μ cyclones in series followed by a glass fiber filter. Both trains had the necessary components to insure all sampling was done isokinetically.

Test Procedures

Sampling was basically conducted using EPA Method 5 procedures with appropriate modifications to accommodate the nature of the process being tested. For safety reasons, the test crew was not allowed to remain at the test location during hot metal addition. Hence, each test (both mass and size) was a single point sample. In order to account for stratification of particulates in the duct, several isokinetic tests were conducted at each of three points (3 ft, 5 ft, 7 ft) in the 10 ft duct. All tests were averaged to determine the mass (and size) concentration and emission rate of particulates generated and captured during hot metal addition. Volumetric flowrate measurements were made prior to the test program under conditions simulating hot metal addition and tapping conditions. The results of these measurements agreed well with the system design data supplied by PECOR. Crewmembers were allowed on the sampling platform during the tapping tests so a total of 12 points were sampled on a horizontal traverse for each test. During each test observers were stationed inside and outside the Q-BOP shop. The observer inside the shop

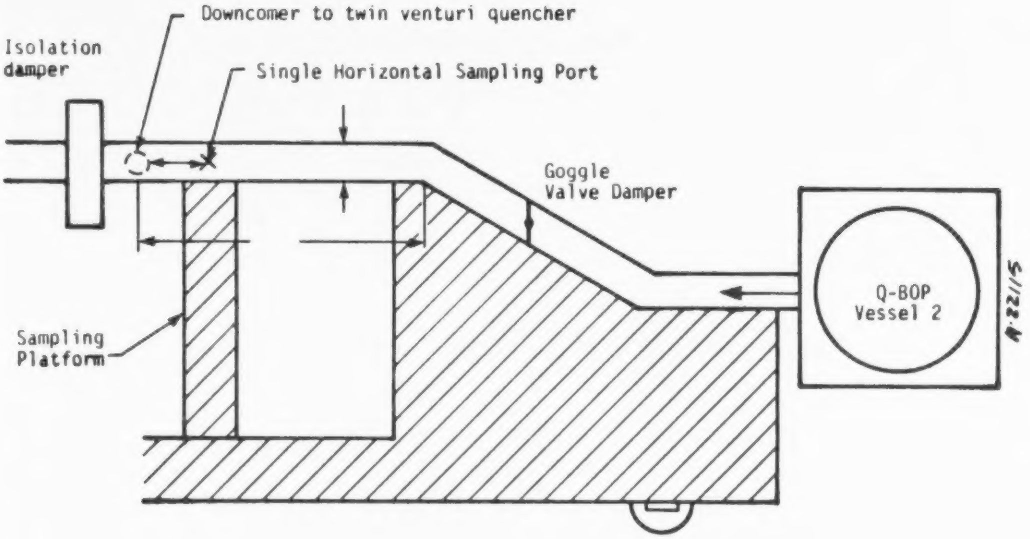
Downcomer to twin venturi quencher
Isolation damper
Single Horizontal Sampling Port
Goggle Valve Damper
Q-BOP Vessel 2
Sampling Platform
N·22115

Figure 3. Sampling location for hot metal addition and tapping.

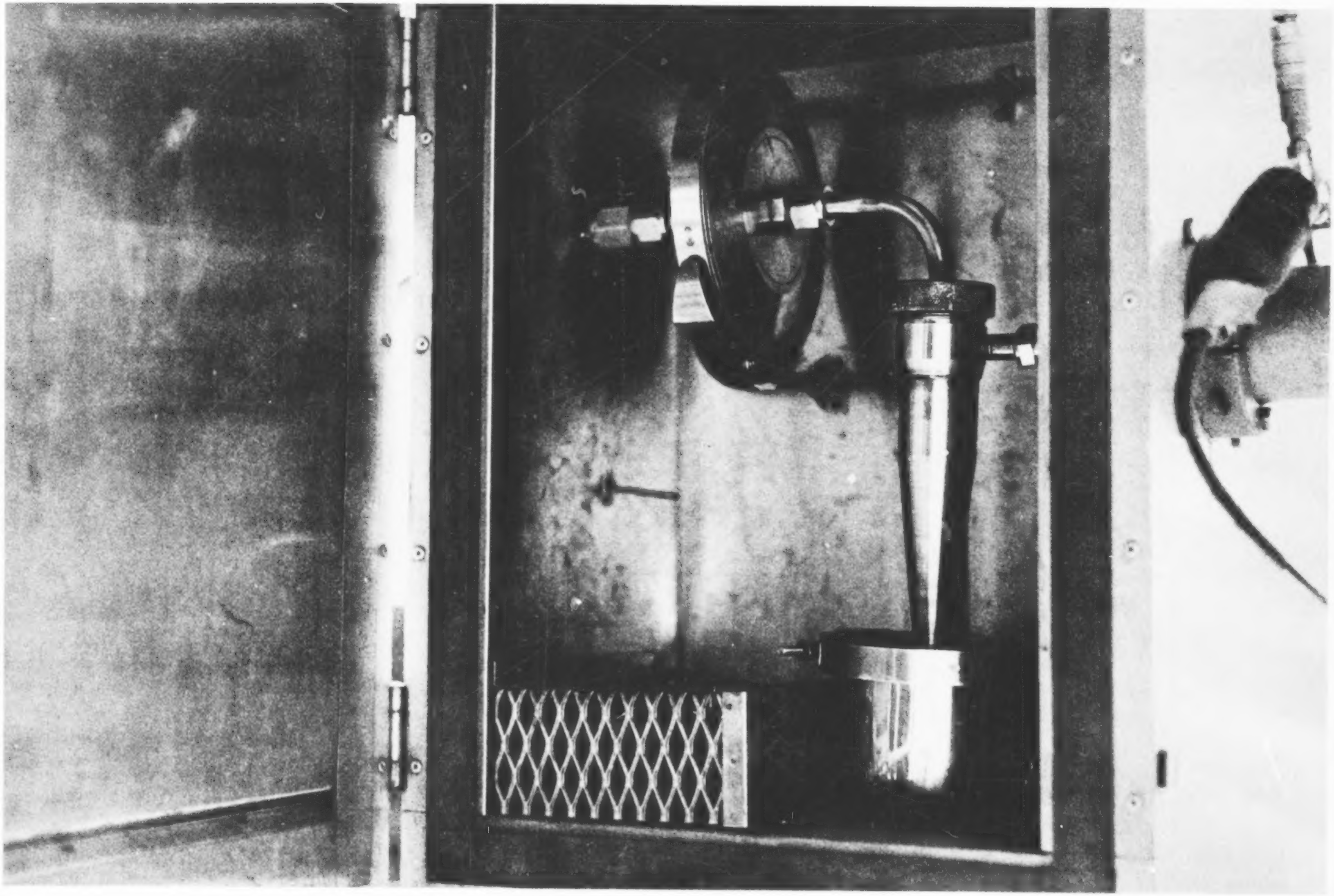

Figure 4. High volume EPA Method 5 mass sampling train.

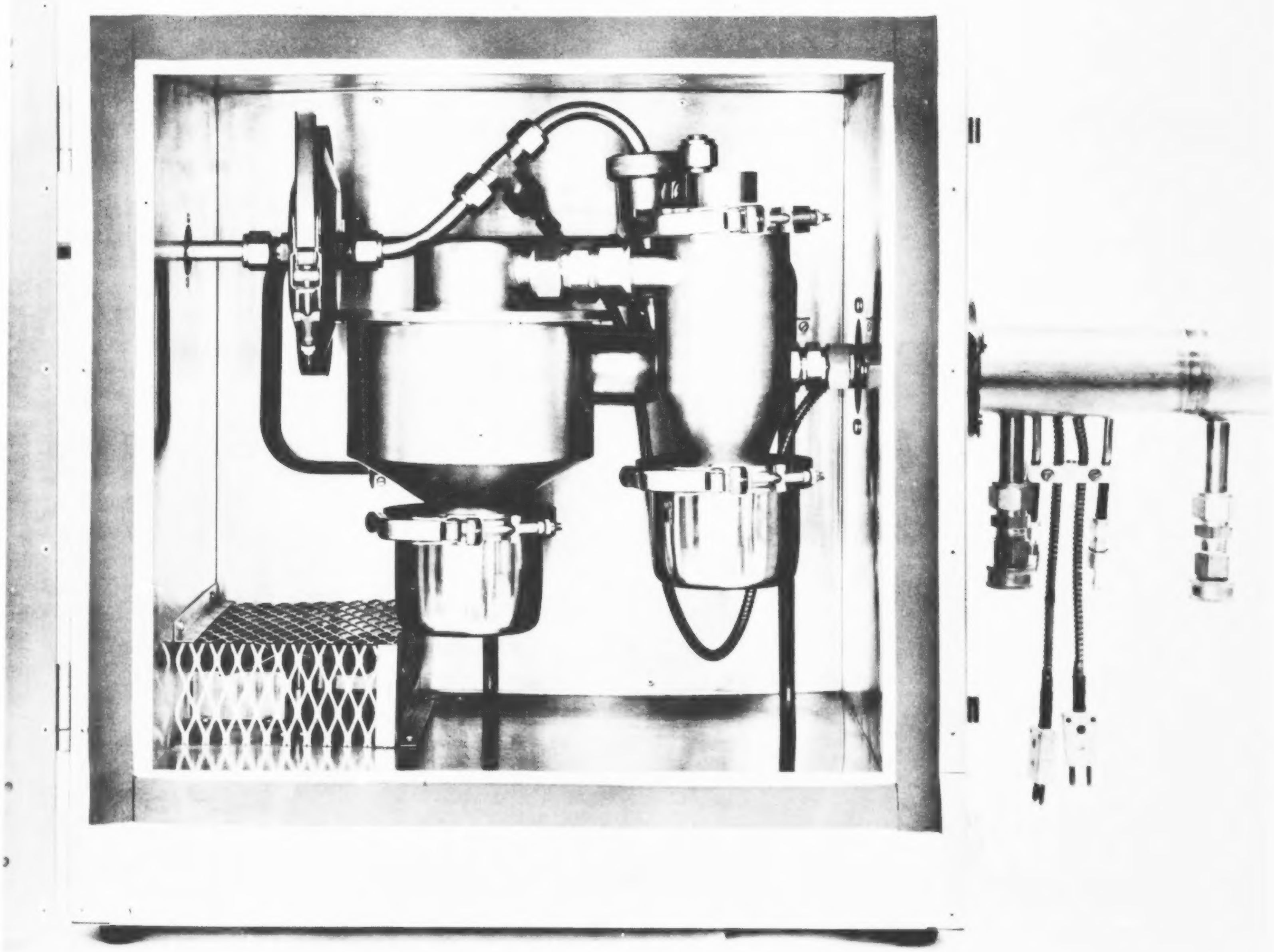

Figure 5. High volume size sampling train.

was responsible for collecting all the heat process information (e.g., scrap type, weight, amount of hot metal charged, temperature, etc.) for qualitatively assessing the collection efficiency of the secondary hood and factors affecting its performance, and for coordinating the entire test program activities with the process operation. The observer stationed outside the shop observed the opacity of any emissions escaping the roof monitor above the vessel being tested (i.e., those fugitive emissions which were not captured by the secondary collection hood). At the completion of a test, samples were recovered from the sampling trains in a room provided by Republic Steel. Both front half and back half sampling train catches were analyzed using the procedures originally proposed by EPA in 1971. Emission factors for hot metal addition and tapping were based on front half catches (nozzle, probe, cyclone, filter) only.

Test Results

Table 1 presents the results of the hot metal addition tests. Approximately 50.2 percent of these emissions were >10.5μ size; 16.5 percent were between 3.6μ and 10.5μ in size; 30.2 percent were between 1.55μ and 3.6μ and 3.1 percent were less than 1.55μ in size. In general, the doghouse and secondary collection hood were capable of collecting almost all of the fugitive particulate emissions generated during hot metal addition provided that the crane operator properly positioned the ladle, and that both ID fans were operating on the secondary hood. Opacity of the emissions leaving the shop roof monitor (i.e., those emissions which escaped collection by the hood) were less than 5 percent. However, when the crane operator was careless or the bell damper (and/or its instrumentation) failed to operate (one fan on secondary hood and one fan on primary hood), the secondary hood failed to capture a significant amount of the fugitive emissions generated which resulted in roof monitor opacities averaging 17 to 19 percent with individual readings as high as 35 percent. No correlation was evident for measured mass emissions with such parameters as type of scrap charged, scrap to hot metal ratio, hot metal charge rate, temperature or composition. High sulfur butts in the scrap charge did result in significant condensible emissions (back half catch).

Table 2 presents the results of the tapping tests. It should be noted that only was ID fan was in operation on the secondary collection hood (the other was drawing on the primary hood). Approximately 86 to 96 percent of the emissions generated during tapping were >3μ in size. In general, the doghouse and secondary collection hood did not quantitatively capture tapping fume. Opacities of the roof monitor emissions averaged 9 percent regardless of whether two ID fans or only one ID fan was drawing on the secondary hood. Since the secondary collection hood is located on the charge side of the doghouse, it was too far away from the teeming ladle to effectively capture tapping fume. Hence, the data reported in Table 2 are underestimated. The type and amount of additives (e.g., desulfurization agent, coke, sulfur, etc.) increased condensible emissions significantly and the measured mass emissions were dependent on tap time (higher mass emissions with short tap times).

TABLE 1. PARTICULATE EMISSION FACTORS FOR HOT METAL ADDITION TO A Q-BOP

	Q-BOP Hot Metal Charge (tons)[a]	Q-BOP Hot Metal Charge Time (min)	Q-BOP Hot Metal Charge Rate (tons/min)	Particulate Emission Rate (lb/min)	Particulate Emission Factor (lb/ton)[b]	Particulate Mass Concentration (gr/dscf)
	201.5	2.2	91.6	111.5	1.2	2.3590
	197.5	2.8	70.5	50.5	0.7	1.0689
	206.0	2.2	93.6	32.0	0.3	0.6788
	202.5	3.4	59.6	33.7	0.6	0.7141
	201.5	2.4	84.0	17.9	0.2	0.3790
	213.0	4.3	49.5	29.5	0.6	0.6260
Average	203.7	2.9	74.8	45.9	0.6	0.9710

[a] Q-BOP hot metal charge (2 ladles per heat)
[b] Lb of particulate emitted per ton of hot metal charged

TABLE 2. PARTICULATE EMISSION FACTORS FOR TAPPING A Q-BOP

	Total Q-BOP Tap (tons)[a]	Total Tap Time (min)	Q-BOP Tap Rate (tons/min)	Particulate Emission Rate (lb/min)	Particulate Emission Factor (lb/ton)[b]	Particulate Mass Concentration (gr/dscf)
	226	4.7	48.0	109.4	2.28	3.8973
	226	6.0	37.6	5.8	0.15	0.3853
	226	5.2	43.4	14.7	0.34	0.6848
Average	226	5.3	43.0	43.3	0.92	1.6558

[a] Average metal tapped per heat (R. Kortge Republic Steel)
[b] Lb of particulate emitted per ton of metal tapped

BOP TEST PROGRAM

Facility Operation

Republic Steel Corporation also operates a two-vessel suppressed combustion BOP shop (250 tons steel/heat) at its Cleveland Works. Each vessel was retrofitted with a doghouse enclosure, and local secondary collection hoods (charging, tapping, other shop operations) which exhaust to a common removal system. Figure 6 illustrates hot metal being charged to the vessel with the doghouse doors open and the secondary collection hood in operation.

At the start of a heat, the doghouse doors were opened and the vessel was rotated toward the charge side. After scrap was charged, the vessel operator initiated the "start charge" mode for the secondary collection hood system which automatically adjusted the dampers to increase flow from 30 percent to approximately 100 percent of capacity (357,800 dscfm). Dampers on other hoods were closed to maximize suction on the secondary charge hood. Figure 7 illustrates the ductwork for the entire secondary collection and gas cleaning system. Scrap was added to the vessel via a charge machine but the secondary collection hood was only at 30 percent of capacity since emissions were minimal. Hot metal (1 ladle) was then added to the vessel using a hot metal ladle and overhead crane. During the test program, the average hot metal addition time was 1.74 minutes and the average amount of hot metal charged was 211.8 tons. Fumes emitted during scrap and hot metal addition were captured by the secondary collection hood on the charge side of the vessel and were ducted to the electrostatic precipitators for removal. Emissions escaping collection by the secondary collection hood drifted upward and entered the atmosphere via the shop roof monitor. After charging was complete, the vessel was turned up to the vertical position for O_2 blow. The doghouse doors were closed and the flow in the secondary system was reduced to 30 percent of capacity to capture any fume escaping the primary hood. After completion of O_2 blow, the vessel was rotated to the tap position. Again, the vessel operator initiated the "start tap" mode, which automatically adjusted the dampers to maximize suction on the tap hood (320,700 dscfm). Fugitive particulate emissions, generated as the steel and additives were poured into the teeming ladle, were captured and sent to the precipitators for removal.

Test Location

The particulate size and mass measurements were made in the ductwork connecting the local secondary collection hoods to the precipitators as illustrated in Figure 8. Two separate sampling ports (~3 ft apart) were used to measure volumetric flowrate and particulate mass concentration simultaneously. These horizontal sampling ports were located approximately 3 diameters downstream and 2 diameters upstream of any flow disturbance. No traversing was done in the vertical direction because extensive and costly modifications were required to support the test crew and equipment. This test location was used for both the hot metal addition and tapping tests. Figure 9 illustrates the actual test location.

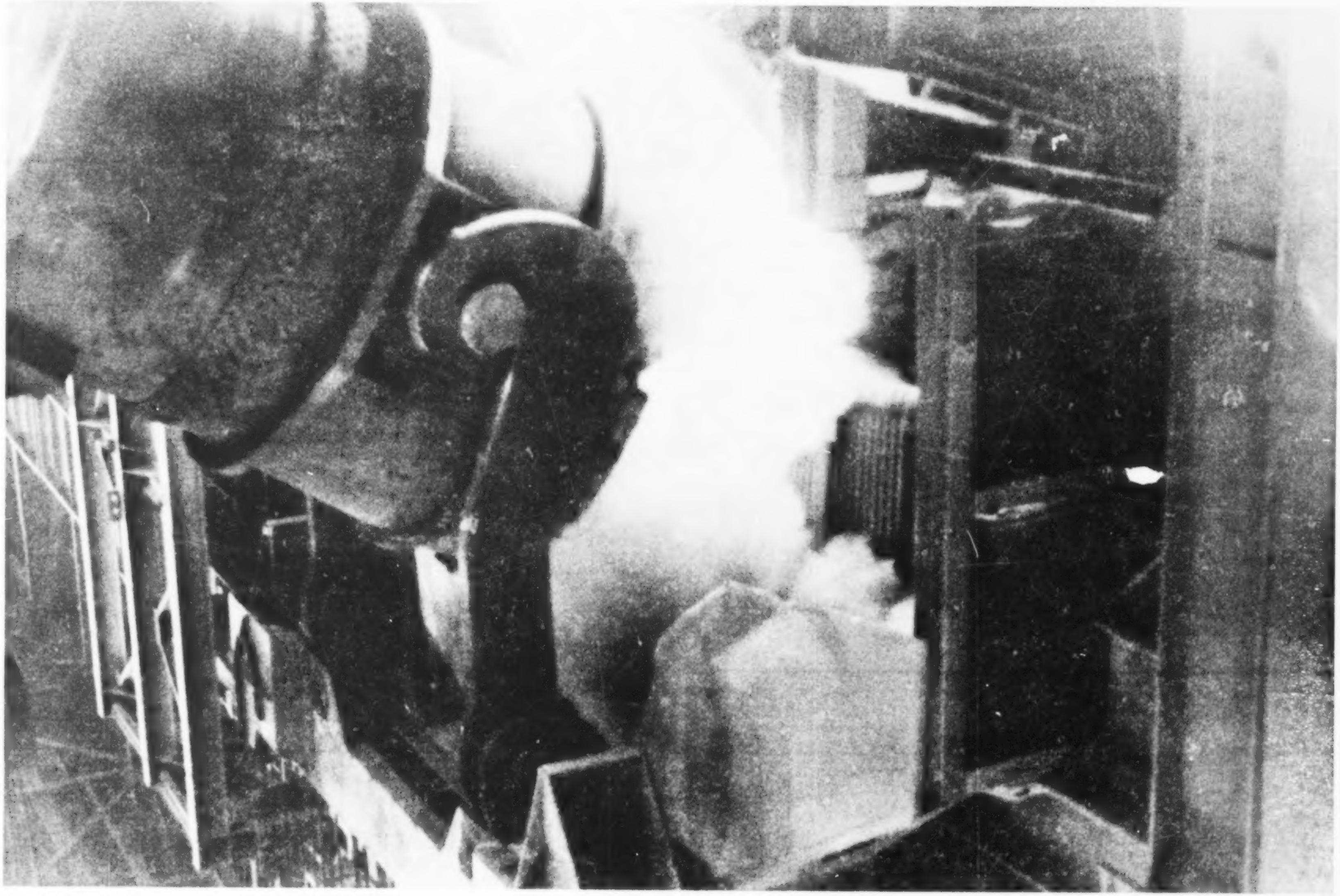

Figure 6. Hot metal addition to BOP at Republic Steel, Cleveland.

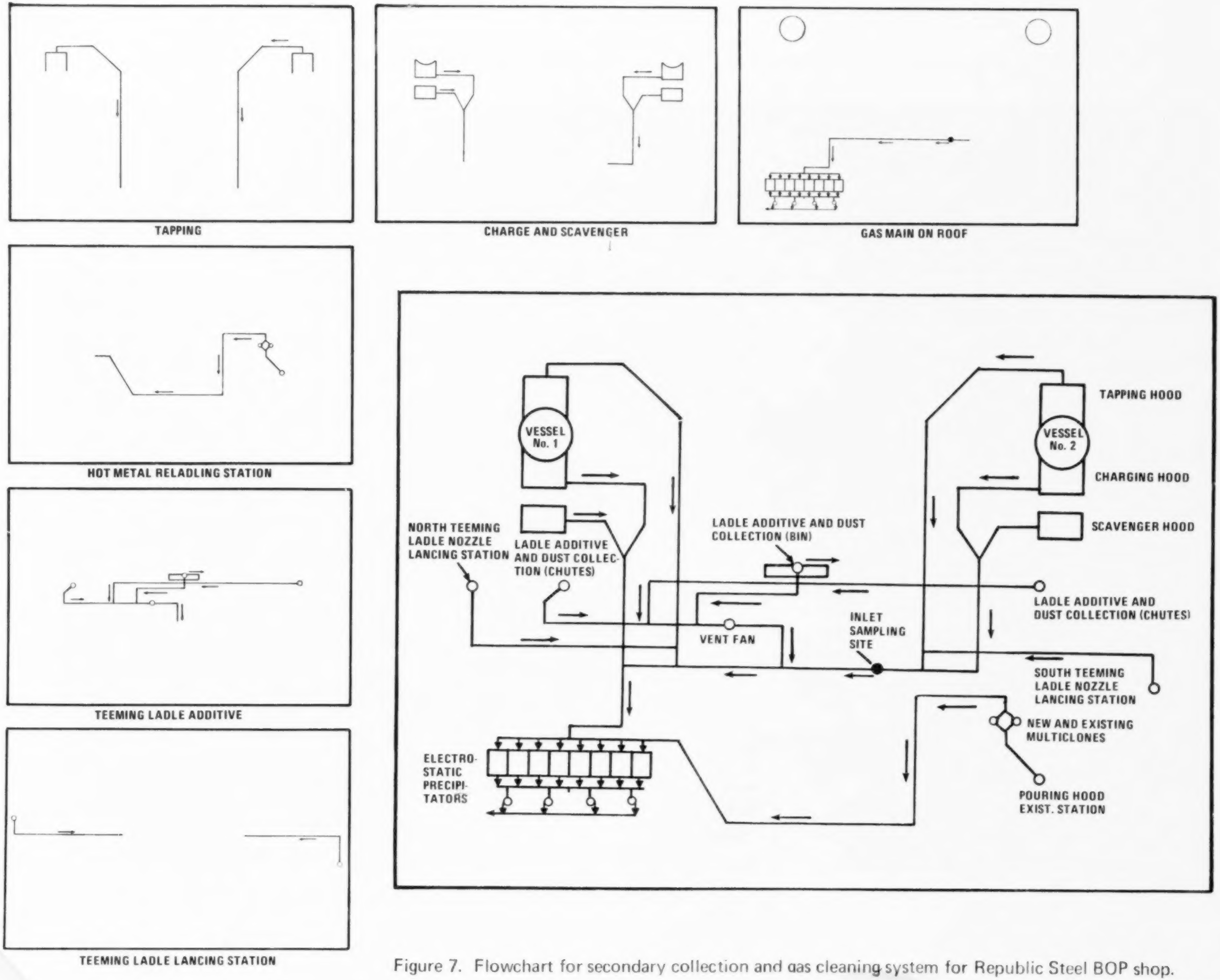
TAPPING
CHARGE AND SCAVENGER
GAS MAIN ON ROOF
HOT METAL RELADLING STATION
TEEMING LADLE ADDITIVE
TEEMING LADLE LANCING STATION
VESSEL No. 1
VESSEL No. 2
TAPPING HOOD
CHARGING HOOD
SCAVENGER HOOD
LADLE ADDITIVE AND DUST COLLECTION (BIN)
NORTH TEEMING LADLE NOZZLE LANCING STATION
LADLE ADDITIVE AND DUST COLLECTION (CHUTES)
LADLE ADDITIVE AND DUST COLLECTION (CHUTES)
INLET SAMPLING SITE
VENT FAN
SOUTH TEEMING LADLE NOZZLE LANCING STATION
NEW AND EXISTING MULTICLONES
POURING HOOD EXIST. STATION
ELECTRO-STATIC PRECIPI-TATORS

Figure 7. Flowchart for secondary collection and gas cleaning system for Republic Steel BOP shop.

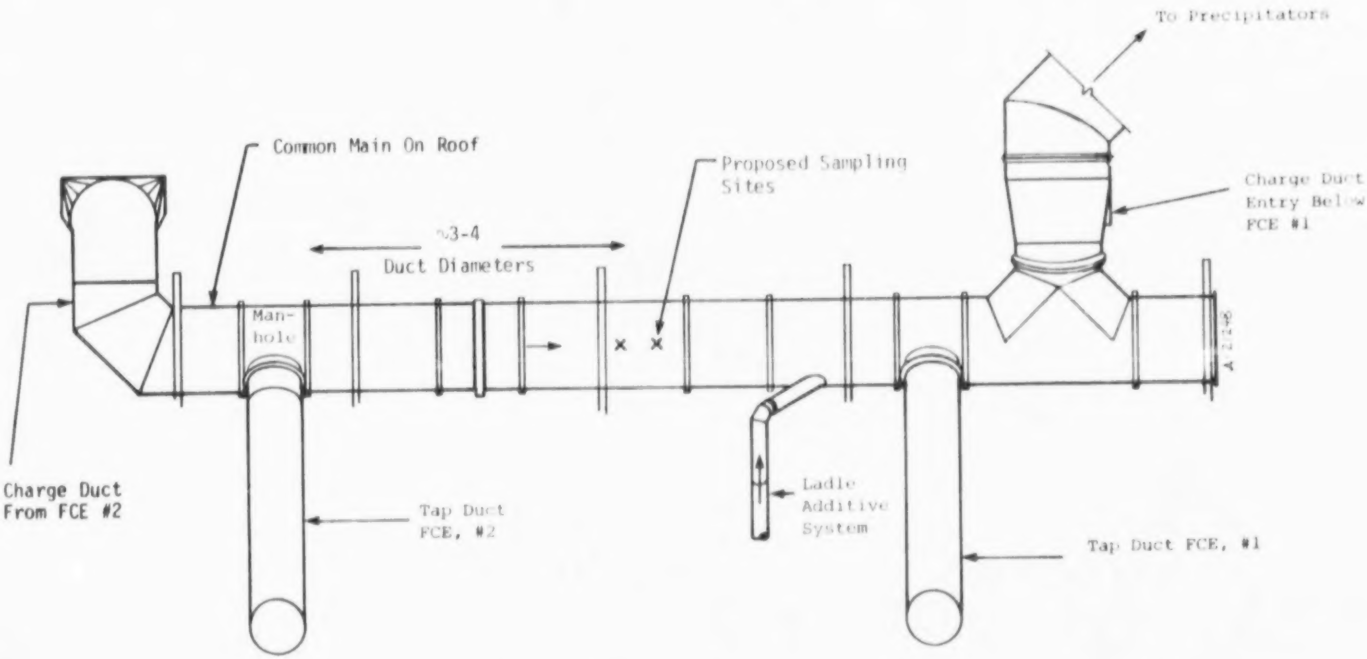
To Precipitators
Common Main On Roof
Proposed Sampling Sites
Charge Duct Entry Below FCE #1
~3-4 Duct Diameters
Man-hole
A-2248
Charge Duct From FCE #2
Tap Duct FCE, #2
Ladle Additive System
Tap Duct FCE, #1

Figure 8. Sampling location for hot metal addition and tapping tests.

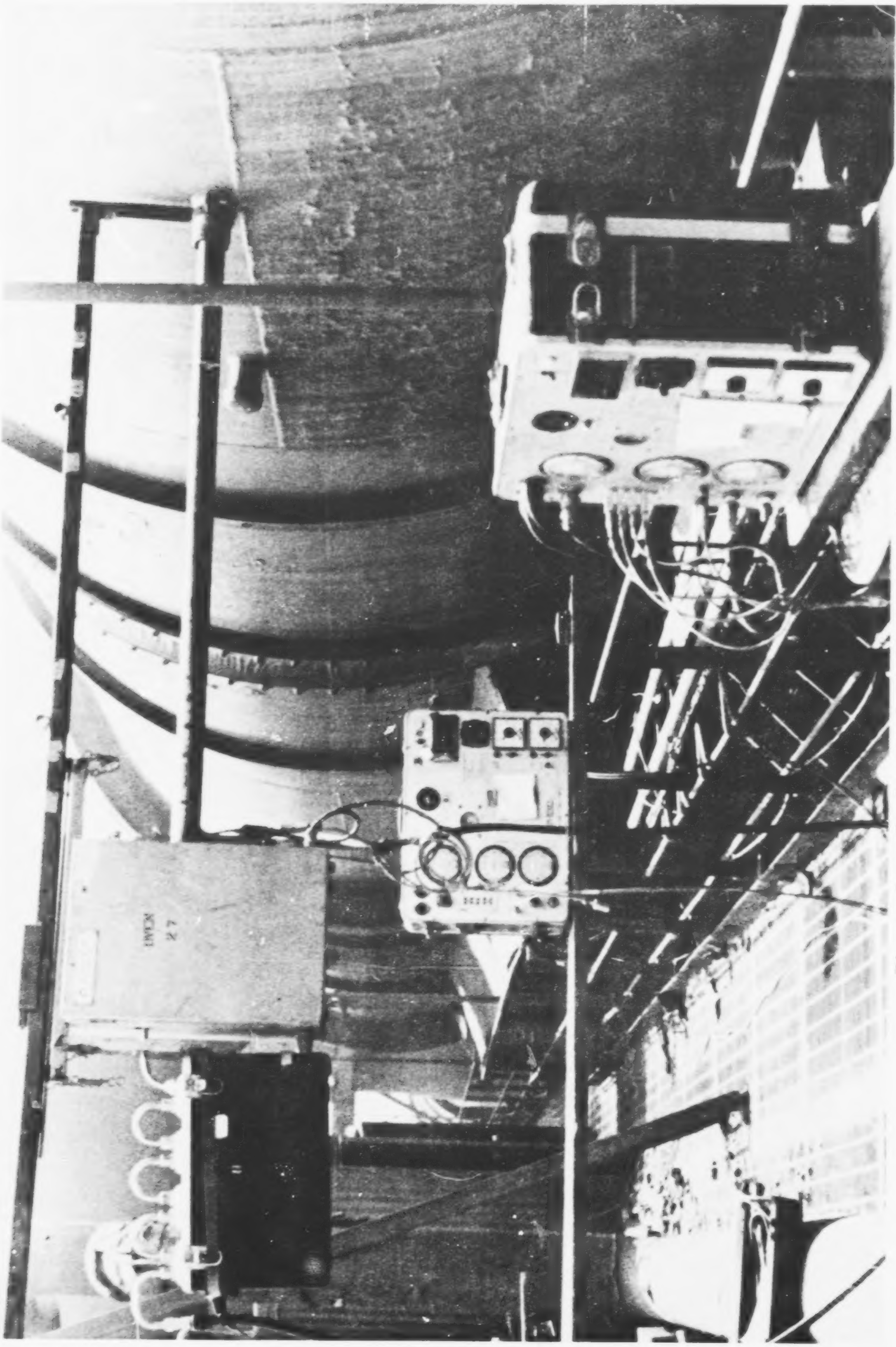

Figure 9. Equipment installed at sampling location.

Test Equipment

The particulate sampling equipment used for this test program was identical to the equipment described previously. In addition, a calibrated S-type pitot tube and thermocouple were used to measure the volumetric flowrate in the duct.

Test Procedures

Sampling was basically conducted using EPA Method 5 procedures with appropriate modifications to accommodate the nature of the process being tested. Since hot metal addition and tapping times were relatively short, it was impossible to traverse the 12 ft duct using the large number of sampling points recommended by EPA Method 2. Hence, volumetric flowrate measurements were made using 6 and 22 points on a horizontal traverse for hot metal addition and tapping respectively. At the same time, particulate mass and size measurements were made at a single point in the duct. To account for stratification of the particulates in the duct, three tests were conducted at each of three points in the duct (3 ft, 6 ft, 9 ft). All tests were averaged to determine the mass (and size) concentration and emission rate of particulates generated and captured during hot metal addition and tapping. During each test, observers were stationed inside and outside the BOP shop. The observer inside the shop was responsible for collecting all the heat process information (e.g., scrap type, weight, amount of hot metal charged, temperature, etc.), for qualitatively assessing the collection efficiency of the local secondary hoods and factors affecting their performance, and for coordinating the entire test program activities with the process operation. The observer stationed outside the shop observed the opacity of any emissions escaping the roof monitor above the vessel being tested (i.e., those fugitive emissions which were not captured by the local secondary collection hoods). At the completion of a test, samples were recovered from the sampling trains in a mobile van provided by Acurex. Both front half and back half sampling train catches were analyzed using the procedures originally proposed by EPA in 1971. Emission factors for hot metal addition and tapping were based on front half catches (nozzle, probe, cyclone, filter) only.

Test Results

Table 3 presents the results of the hot metal addition tests. Approximately 67.6 percent of these emissions were $>10.5\mu$ size; 13.7 percent were between 3.6μ and 10.5μ in size; 7.3 percent were between 1.5μ and 3.6μ, and 11.5 percent were less than 1.55μ in size. In general, the doghouse and secondary collection hood were capable of collecting all of the fugitive particulate emissions generated during hot metal addition provided the vessel operator initiated the "start charge" mode earlier enough to insure maximum suction on the charge hood prior to actual hot metal additions. Opacity of the emissions leaving the shop roof monitor (i.e., those emissions which escaped collection by the hood) were much less than 5 percent. However, when the vessel operator did not initiate the "start charge" mode soon enough, the opacity of roof monitor emissions reached a maximum of 10 percent. There did not appear to be a correlation

TABLE 3. PARTICULATE EMISSION FACTORS FOR HOT METAL ADDITION TO A BOP

	Hot Metal Charged (tons)	Duration of Charge (min)	Hot Metal Charge Rate (tons/min)	Particulate Mass Emission Rate (lb/min)	Particulate Emission Factor (lb/ton)	Particulate Mass Concentration (gr/dscf)
	198.5	1.16	170.1	40.0	0.24	0.698
	218.0	1.50	145.3	23.9	0.16	0.570
	215.0	3.21	66.8	21.1	0.32	0.373
	209.5	1.66	125.7	22.3	0.18	0.466
	208.5	2.38	87.4	22.7	0.26	0.408
	216.5	1.31	164.4	44.1	0.27	0.989
	217.0	1.75	123.9	33.2	0.27	0.606
	222.5	1.25	177.9	56.9	0.32	1.056
	201.5	1.40	143.6	34.3	0.24	0.717
Average	211.8	1.74	133.9	33.2	0.25	0.654

between process parameters and measured mass emissions, although the presence of oily scrap (e.g., turnings, trimmings) increased condensible organic emissions significantly. High emission rates of condensible inorganics and sulfates also occurred but insufficient information on scrap composition resulted in no definite correlations.

Table 4 presents the results of the tapping tests. Approximately 59.8 percent of these emissions were >10.5μ in size; 13 percent were between 3.6μ and 10.5μ in size; 8.6 percent were between 1.55μ and 3.6μ, and 18.6 percent were less than 1.55μ in size. In general, the tap hood captured almost all of the fugitive emissions but the unhooded manual charge chute contributed the majority of emissions observed leaving the roof monitor. Opacities averaged 2 percent but reached a maximum average of 9 percent on one occasion because the vessel operator failed to initiate the "start tap" mode in time. There did not appear to be a correlation of measured mass emissions with process variables but condensible emissions were influenced considerably with the addition of such additives as coke or sulfur.

TABLE 4. PARTICULATE EMISSION FACTORS FOR TAPPING A BOP

	Duration of Tap (mins)	Hot Metal Tapped (tons)	Hot Metal Tap Rate (tons/min)	Particulate Mass Emission Rate (lb/min)	Particulate Emission Factor (lb/ton)	Particulate Mass Concentration (gr/dscf)
	10.23	249.0	24.3	4.3	0.18	0.101
	9.00	248.0	27.5	3.5	0.13	0.082
	10.08	270.5	26.8	3.5	0.13	0.081
	8.12	269.0	33.1	7.3	0.22	0.160
	6.57	240.0	36.5	6.9	0.19	0.147
	7.00	259.5	37.1	8.9	0.24	0.187
	6.50	252.0	38.7	2.1	0.05	0.048
	4.58	198.5	43.3	4.2	0.10	0.102
	6.00	257.5	42.9	7.9	0.18	0.135
Average	7.56	249.3	34.5	5.4	0.16	0.116

REFERENCES

1. Steiner, J., and Knirck, J., "Particulate Matter Emission Factor Tests for Q-BOP Hot Metal Addition and Tapping Operations at Republic Steel Chicago, Illinois," Acurex Report TR-78-143, Volume I, November 1978.

2. Steiner, J., and Pape, R., "Particulate Matter Emission Factor Tests for BOP Hot Metal Charging and Tapping at Republic Steel Cleveland, Ohio," Acurex Report TR-79-23/EE, Volume I, September 1979.

Session 2: WATER POLLUTION ABATEMENT

Chairman: Gary A. Amendola, Chief
Technical Support Section
Region V, EPA
Eastern District Office
Westlake, OH

Steel, Water, Regulations, & Etc.

by

Robert B. Schaffer, Director
Effluent Guidelines Division

and

Edward L. Dulaney, Project Officer
Steel Industry Study

Good afternoon ladies and gentlemen. I am Bob Schaffer, Director of the Effluent Guidelines Division of the United States Environmental Protection Agency and I am here to give you a brief rundown on the activities in our Division, particularly as they relate to the iron and steel industry.

The steel industry regulations promulgated by the Division in 1974 (Steelmaking segment) and 1976 (Forming, Finishing, and Specialty segment) in response to the passage of the Clean Water Act of 1972 were remanded to the Agnecy for further work by the Third Circuit Court of Appeals in Philadelphia in 1975 and 1976, respectively. At the same time, the Agency was in the process of working out a Consent Agreement with the Natural Resources Defense Council relative to a more careful evaluation of toxic pollutants in industrial effluents.

Thus, in response to the remands and the consent agreement, the Division initiated a new and more thorough study of the steel industry. The field work of this new study has now been essentially completed although a few special studies to check specific points in question continue.

We have received roughly two thousand (2000) responses to questionnaires so, as directed by the Court, we have acquired a great deal of specific information about steel industry operations. These operations break down into twenty major subcategories (See Attachment I).

Since we will be writing regulations on the basis of Best Practicable (BPT), Best Available (BAT), Best Conventional (BCT), Best Demonstrated (BDT), and Pretreatment for New Source (PSNS) and for existing sources (PSES) for these 45 subsets we have a great deal of regulation writing to do.

What we have found from surveying the industry is that about thirteen percent of the operations discharge to publicly owned treatment works, although in general these are the smaller operations. In addition, about twelve percent of the operations reported achieving zero discharge.

Water use rates in this industry are very high but much of that water use is for non-contact cooling purposes and is not significantly contaminated in use except by the addition of heat. Since the impact of heated discharges is so site specific, this Division has not attempted to address thermal discharges as a part of the steel industry effluent regulations on a national basis. To give you some idea of the impact of effluent regulations on contact or process wastewater volumes though, let me point out that the remanded regulations were expected to result in a 96% reduction in the "once-through" applied rate of 5500 MGD.

With the sensitivity of todays testing methods, we find toxic pollutants, conventional pollutants, and "other" pollutants in just about every waste soruce. But, toxic organics in the milligram per liter range have been found primarily in coke plant wastes as expected and toxic metals in this range have been found primarily in the steelmaking operations discharges. See Attachment No. 2

The treatment technologies that hold greatest promise for this industry are first of all clarification and flow reduction, i.e., recycle or cascade rinsing, biological oxidation of coke plant wastes, additional blowdown treatment for discharge (lime or sulfide precipitation), and carbon adsorption.

We are currently in the process of preparing a draft report in nine volumes summarizing what we have found so far. Several volumes are already at the printers and the remainder are to be printed before the end of the year. We expect to distribute these reports to a limited list of recipients starting December 1, 1979 with the volumes then available. Thirty days after the last distribution we expect to hold an informal public comments meeting to give interested parties an opportunity to further explain their written comments.

Since our technical study has developed treatment alternatives and the relative costs and effectiveness of these alternatives, we are now moving into the phase of selecting the alternative to be used as the basis for the regulations. In this phase we will be working closely with the economic evaluations program on two levels. A linear programming analysis will be utilized to optimize the pollution control achievable by the application of any given level of capital investment by comparing the effectiveness of treatment versus its cost between the various waste sources. Secondly, the overall economic impact on the industry will be evaluated in the final selection of the treatment alternatives to be designated as the basis for the regulation. Our current schedule for this work is to propose a regulation in August of 1980 and to promulgate the regulation in March of 1981.

Attachment No. 1

Iron and Steel Industry

Subcategorization

20 Subcategories - 45 sub-subcategories

- By-Product Coke
- Beehive Coke
- Sintering
- Blast Furnace: Iron
  : Ferromanganese
- Basic Oxygen Furnace: Semi-wet Air pollution Control Methods
  Wet Air Pollution Control Methods:
    Open Combustion Systems
    Suppressed Combustion Systems
- Open Hearth Furnace: Semi-wet Air pollution Control Methods
  Wet Air Pollution Control Methods
- Electric Arc Furnace: Semi-wet Air Pollution Control Methods
  Wet Air Pollution Control Methods
- Vacuum Degassing
- Continuous Casting
- Hot Forming - Primary
- Hot Forming - Section
- Hot Forming - Flat (Plate, and Hot Strip and Sheet)
- Pipe and Tube - Hot and Cold Worked
- Pickling - Sulfuric Acid (Batch and Continuous) (Neutralization and Recovery)
- Pickling - Hydrochloric Acid (Batch and Continuous) (Neutralization and Regeneration)
- Cold Rolling (Direct Application, Combination, and Recirculating)
- Hot Coatings: Glavanizing
  Terne
  Other
- Combination Acid Pickling - (Batch and Continuous)
- Scale Removal: Kolene and Hydride - Batch and Continuous)
- Alkaline Cleaning (Batch and Continuous)

Attachment No. 2

Iron and Steel Industry

Raw Waste Concentrations

Subcategory	Organics mg/l(1)	Metals mg/l(1)	Others	
A By-Product Coke				
1 WAL (41 GPT)	466 (12)	87(2)	8000	NH_3, ØH, S, SCN, O&G, TSS, CN
2 FC Bldn (70 GPT)	161 (8)	-	290	ØOH, SCN, NH_3, O&G TSS, S
3 Benzol (73 GPT)	223 (7)	-	1160	ØOH, SCN, NH_3, S, O&G TSS, CN
C Sinter (3 pl.)	*	*	2185	TSS, O&G, F
D Blast Furn. (4 pl)	7.5 (3)	40 (1)	2684	TSS, O&G, F ØOH
E BOF (4 pl.)				
1 Open C.	*	22(3)	4007	TSS, F
F Open Hearth	*	389(1)	613	NO_3, F, TSS
G EAF	*	109(6)	2761	TSS
H Vac. Degas.	*	5(2)	28	TSS
I Cont. Casting	*	*	24	TSS, O&G
J, K, L Hot Forming:				
J Primary	*	*	157	TSS, O&G
K Section	*	*	91	TSS, O&G
L Flat: Plate	*	*	116	TSS, O&G
: HS&S	*	*	60	TSS, O&G
M Pipe & Tube				
Hot Worked Cold Worked	*	*	107	TSS, O&G
N Cold Rolling:				
Direct App	*	*+Fe	2150	O&G, TSS
Recirculated	45 (4)	7.2 (3)+Fe	42767	O&G, TSS

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* Less than 1 mg/l

(1) Sum of concentrations of those present in average at more than 1 mg/l and the number of pollutants found in that amount

TOTAL RECYCLE OF WATER IN INTEGRATED STEEL PLANTS

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Abstract

An engineering study was performed to determine the facilities necessary to achieve total recyle of water for five integrated U.S. steel plants. The study was in fulfillment of Contract No. 68-02-2626 issued by the USEPA, Metallurgical Processes Branch, Industrial Processes Division, IERL, RTP, North Carolina. Conceptual engineering of facilities required to reach both BAT and the goal of total recycle was performed. Capital and operating costs were estimated and energy requirements developed. Technologies were compared and the most promising were selected as being applicable.

This paper summarizes the findings and recommendations from the study and identifies problems expected to be encountered. These problems included the necessity for development and verification of technologies to treat the individual wastes and combinations of wastes, environmental impacts of increased off-site power generation, additional fuel requirements and the necessity of increased solids disposal.

Estimates of increased steel costs, increased electrical energy demands and the demand for additional fuels are specified. The paper presents data that should be contemplated by industry, environmental groups and regulatory agencies in their efforts to arrive at environmentally sound and practical effluent requirements.

TOTAL RECYCLE OF WATER IN INTEGRATED STEEL PLANTS

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In 1972 Public Law 92-500 set as a national goal zero discharge of pollutants by the year 1985. If this goal were to be attained many industries would have to upgrade their water systems drastically and, in some cases, provide systems utilizing total recycle of water. The steel industry is the single largest user of water in the United States and installing systems for total recycle is a tremendous task. To determine the magnitude of this undertaking the USEPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC commissioned Hydrotechnic Corporation to conduct a study of total recycle of water in five integrated steel plants with an intermediate step to attain present BAT requirements.

Five plants were selected for study based on a number of criteria. These plants were:

Inland Steel Corp	- Indiana Harbor Works
USSC	- Fairfield Works
Kaiser Steel Co.	- Fontana Plant
National Steel Corp.	- Weirton Steel Division
Youngstown Sheet & Tube Corp.	- Indiana Harbor Works

The location of the plants is shown on Figure I.

The plants represent a diverse cross-section of industry in relation to factors that would influence the installation of wastewater control equipment. The plants varied not only in production tonnage but also in physical size. Wastewater control facilities installations ranged from those practically complying with BAT to those that required facilities to attain BPT. Some plants were spread out and others built on compact sites so that the production in tonnage per acre was from low to very high. Their water sources were from rivers, the Great Lakes and from wells. We think a fair cross-section of steel plant conditions was considered.

The plants selected were then visited to obtain information on:

- water, air and production process flow diagrams of each production facility;
- plot plans of the plants indicating areas that would be available for the construction of pollution control facilities;
- an indication of facilities the plant has planned for future installation or deletion;
- efficiencies of water pollution and air pollution control facilities presently installed;
- areas of typicality (or atypicality) of the plant;
- any constraints that may be placed on the installation of future pollution control facilities.

After the initial visit, the data collected were analyzed and process water flow diagrams were prepared for each plant.

The five selected integrated steel plants were studied to determine: similarity of wastes and production processes between integrated steel plants, problems that would be encountered with respect to site specifics, water uses in various plants, degrees of treatment currently practiced and applicability of retrofit of treatment processes to plant production operations and plant waste treatment processes.

POSSIBLE PLANS FOR PLANTS TO MEET BAT AND TOTAL RECYCLE

Plans and designs were prepared for each of the five plants to achieve the objectives of both BAT and total recycle. Although the plans take location factors into account, they are conceptual and contain a number of assumptions about physical constraints which may exist that will preclude the use of the suggested systems as presented. In addition, various mixes of wastes were conceptualized for concurrent treatment which have not been previously demonstrated. If implementation of any of the programs presented is planned, comprehensive testing should be undertaken prior to the design of the systems. After design and construction, the operators of the facilities should be of a competence level that will ensure proper operation of the facilities.

For each of the systems developed seven basic premises were assumed necessary for satisfactory operation; these are:

1. All non-contact cooling water and storm water must be segregated from process flows to minimize the amount of wastewater to be treated.

2. Discharge of non-contact cooling water would be permitted under BAT. For total recycle, except in the case of Kaiser-Fontana, two steps were used, one

allowing the non-contact cooling water to discharge under total recycle conditions and the other requiring cooling and total recirculation of all non-contact cooling water.

3. Storm water runoff from material storage piles would be collected and stored in lined ponds and gradually discharged to receiving waters under BAT conditions and to treatment facilities to condition the water for recycle under total recycle conditions.

4. Water with high levels of dissolved solids could not be used to quench coke and slag because of the resulting air pollution problems.

5. Scrubber cars would be utilized at the pushing side of the coke ovens.

6. The discharge of industrial wastes to municipal treatment plants would be discontinued necessitating their treatment at the plant under total recycle conditions.

7. General area runoff and treated or untreated sanitary wastes would discharge from the plant to either receiving water or municipal treatment plants.

In the preparation of cost estimates, broad assumptions had to be made as to the costs of yard piping, both underground and aboveground, since detailed knowledge of interferences that might be encountered were not available. Capital and operating costs were based on the use of purchased electrical power and natural gas as the energy source for the evaporation of residual waste streams. Equipment costs were obtained from manufacturers and from in-house data.

Since the systems for the five plants are quite complicated this paper will only deal with generalities. Anyone desiring a more detailed analysis of the systems proposed for the five plants should refer to the final report prepared for this project.

BAT

Figure 2 is a schematic flow diagram of a "typical" integrated steel plant showing the facilities required to attain the BAT requirements. Since BAT has never been officially promulgated and is now being developed, a number of assumptions were made in defining BAT for this report. This diagram shows a typical integrated plant divided into six separate production areas for simplicity. These areas and their water systems are as follows:

1. Coke and By-Products Plant
   All water discharged from the coke and by-products plant would be treated with free and fixed ammonia stills and a biological treatment plant prior to discharge. In most cases, concurrent treatment of the blowdown from the blast furnace gas washer system was recommended since this gas is basically a dilute form of coke plant wastes. However, prior removal of toxic metals in the blast furnace wastewater may be required.

2. Iron Making and Sinter Plant
   The sinter plant system should be "bottled-up" as much as possible and any blowdown should have suspended solids removal. This can be accomplished by separate

settling facilities or by directing the blowdown to the blast furnace thickeners. As discussed under the coke plant section, the blast furnace blowdown if low enough in toxic metals content, should be compatible for treatment with the coke and by-products plant wastes in a biological treatment plant prior to discharge. If this proves impossible, separate treatment consisting of alkaline-chlorination and/or lime precipitation will be required.

3. Steel Making

   The gas washing wastewater would be recycled through a thickener for solids removal and a portion discharged as blowdown.

4. Primary Hot Forming

   Recycle systems utilizing scale pits, settling basins, filters or clarifiers and cooling towers prior to recycle were selected. A treated blowdown would be discharged to the receiving water.

5. Secondary Hot Forming

   The BAT systems envisioned for secondary hot forming utilize a minimum blowdown after treatment in scale pits, settling basins, filters or clarifiers and cooling towers.

6. Cold Finishing

   There are varied facilities included under the cold finishing subcategory and most produce wastewater discharges that cannot be recycled further due to high dissolved solids concentrations. The classical method of treatment is coagulant addition, neutralization, aeration, polymer addition followed by settling in flocculator clarifiers. This method was adopted for treatment of mixtures of cold finishing mill wastewaters.

The original electroplating facility regulations before being remanded call for zero discharge of wastewater. Since these regulations were based on small plating shops the application of this standard to the much larger integrated plant operations is questionable. However, facilities have been included to demineralize electroplating facility blowdown for recycle to attain zero discharge.

Total Recycle

Two premises were investigated to arrive at total recycle systems. The first did not include control of non-contact cooling water since, at present, the effluent guidelines do not regulate these water systems. The second, included control of non-contact cooling water since regulations could conceivably be formulated to include the control of this water. Figure 3 is a schematic flow diagram of a "typical" integrated steel plant showing facilities necessary for total recycle. Because of the build-up of scale in tight recycle systems due to high dissolved solids, all blowdown water is collected and conveyed to one or more demineralization plants for dissolved solids removal. A dissolved solids level in the product water was set at 175 mg/l and in many cases only a portion of the waste water would require the demineralizator process.

If non-contact cooling water is included the blowdown would increase and, in turn, the size of the demineralization facilities.

Treatment Processes

We have not explored the various treatment processes for the treatment of the various wastewaters generated in an integrated steel plant in this paper; however, the process to demineralize the water deserves some discussion since this technology would be a primary technical and cost consideration in a total recycle scheme.

Dissolved Solids Removal

Various pretreatment and treatment processes were investigated for use in the removal of dissolved solids. Based on this investigation four more processes were considered. The results of costs for the processes are presented on Table I.

Because of extremely high costs of energy requirements, total evaporation was eliminated. Ion exchange was eliminated from consideration on the basis of applicability, annual costs and off-site land requirements. Thus only reverse osmosis and electrodialysis remained for further consideration. At this time, reverse osmosis enjoys a broader technological base and has been used in more applications than electrodialysis. Reverse osmosis was, therefore, selected as the possible dissolved solids removal treatment unit operation for our analyses, in spite of the higher capital and operating costs.

SUMMARY AND CONCLUSIONS

No simplified solutions can be developed that would be applicable throughout the entire industry. The atypical nature of the plants studied, and other differences throughout the entire industry, makes it difficult to assign standard numbers to water flows, costs and various other factors that would prove extremely convenient for determining restrictions on contaminant levels and the cost of complying with these restrictions. For this reason, five plants were examined to quantify the various considerations.

The total capacity of the five plants studied was approximately 19.3 kkg (21.2 million tons) per year which represents 13.5 per cent of the total present integrated steel plant capacity in the United States. The diversified nature of the integrated steel plants would probably be more pointed if additional plant studies were conducted.

COSTS

Cost estimates were prepared for the proposed systems to accomplish total recycle with the interim step of reaching the BAT requirements. Both capital and annual costs were estimated using 1978 prices. Since only general designs were prepared, certain site specific considerations, such as the need for piling, obstructions, railroad crossing, etc., may not have been taken into consideration. However, contingency factors were added in an attempt to compensate for unknown and unforeseen items which would cause cost increases.

Table II presents the estimated costs for both BAT and total recycle. Natural gas was assumed as the fuel. In addition, costs per kkg (ton) of steel produced to achieve both BAT and total recycle are presented.

It would be expected that the costs to achieve both BAT and total recycle for each plant on the basis of cost per unit of production of steel would be approximately the same. However, noticeable differences are evident.

The BAT compliance step presented the most differences in the facilities needed as well as their construction and operating costs. This was due to the great variety in the wastewater treatment and recycle systems presently installed. These differences are mainly due to the degree of existing control facilities installed, the availability of water for use in the plants and, in some cases, the States in which the plants are located.

BAT Costs

The following costs per unit of production were estimated to achieve the BAT requirements.

	Costs per kkg (ton)
Kaiser-Fontana	No costs estimated.
Inland-Indiana Harbor	$1.91 (1.73)
National-Weirton	$2.63 (2.39)
USSC - Fairfield	$2.52 (2.28)
Y.S. & T. Indiana Harbor	$3.95 (3.58)

The costs for Kaiser-Fontana were not estimated for the BAT step because this plant has facilities which, with some modifications, would bring it into compliance. Of the costs for the four remaining plants Fairfield, Weirton and Y.S. & T. Indiana Harbor are basically in agreement. The cost for Inland Steel, however, is approximately half that of the other three plants and this is probably due to two factors. The main factor is that Inland does not have tinning facilities which require high cost treatment facilities and high operating costs, since zero discharge is required for BAT. Another reason could be the size of this plant which produces almost twice as much steel as the next largest plant studied, namely Y.S. & T. -

Indiana Harbor Works. The large plant would, in all probability, have treatment facilities with lower unit capital and operating costs.

Total Recycle Costs

The following costs per unit of production for facilities to achieve total recycle, with and without the inclusion of non-contact cooling water were estimated. These costs include the costs for the BAT step as shown above.

	Cost per kkg (ton)			
	Without Non-Contact Cooling Water		With Non-Contact Cooling Water	
Kaiser-Fontana	-		$ 2.99	(2.71)
Inland-Indiana Harbor	$ 7.63	(6.92)	14.18	(12.86)
National-Weirton	32.11	(29.13)	33.21	(30.13)
USSC-Fairfield	-		31.41	(28.49)
Y.S. & T.-Indiana Harbor	9.87	(8.96)	10.77	(9.77)

The low cost per unit of production for the Kaiser-Fontana plant can be attributed to their presently installed system which produces the lowest blowdown amount per unit of production of any of the plants studied and is probably one of the lowest in the world.

The degree of existing control facilities installed is an important consideration since the newer plants, due to the technology not previously available and to recent concerns for protecting the environment, installed facilities to treat their wastewater to a degree which usually meets the BPT requirements and, in some cases, even the BAT limitations. Plant locality also has a great effect since plants located near abundant supplies of water were more apt to exclude facilities for wastewater treatment and reuse.

The State in which a plant is located also has an effect since, prior to the formation of the U.S.E.P.A., the States were the sole governing bodies that determined the extent to which a particular plant had to reduce its discharge of contaminants. In some States the restrictions were stricter, thus resulting in steel plants with more treatment facilities than those required in other States.

Increase in the Cost of Steel

In 1978 steel products ranged in cost from approximately \$385 to \$440 per kkg (\$350 to \$400 per ton). This variation is due basically to the wide range of products offered. A cost of \$413 per kkg (\$375 per ton) has been used as an average in order to calculate the cost of the various steps on the price of steel. The added cost due to BAT will be approximately \$2.67 per kkg (\$2.42/ton). Total recycle, excluding non-contact cooling water, will cost approximately \$13.15 per kkg (\$11.93 per ton) and total recycle including non-contact cooling water will cost approximately \$16.91 per kkg (\$15.34 per ton). This represents an increase of 0.65 per cent in the cost of raw steel produced for BAT, 3.2 per cent for total recycle excluding non-contact cooling water and 4.1 per cent for total recycle including non-contact cooling water.

IN-PLANT EFFECTS

The goals of BAT and total recycle would result in large expenditures for the construction of water treatment and reuse systems. These large construction projects, if implemented, will most probably have a disrupting effect on the operations of the steel plants during construction and, in some of the more crowded plants, even after the construction is completed.

The transportation of chemicals, sludges, oils, etc., within the plants would increase with inherent increased traffic problems. Safety requirements would require broadening to encompass the use of different chemicals and the use of new types of water treatment process equipment. Monitoring of water systems would be expanded so that water qualities of the tightly "bottled-up" systems are not upset causing outages of production facilities.

The management of sophisticated water systems in well diversified integrated steel plants would in itself be an extremely complex problem.

EXTRA-PLANT EFFECTS

Whenever extensive and ambitious projects are undertaken in an industrial plant or in an industry as a whole, effects of these projects are felt not only within the plant or industry itself but also external to the plant.

Power Generation

It has been assumed that the electric power required to operate the facilities for attaining BAT and total recycle would be generated off-site. An average of the power required for BAT and total recycle including NCCW for the four most "typical" plants is 57.5×10^6 j per kkg (14.5 kWh per ton) and 262 j per kkg (66 kWh per ton), respectively. If this average is applied to the total U.S. steel industry, a total of 260 MWe and 1,183 MWe of new generating capacity will be required for BAT and total recycle, respectively. Implementation of total recycle were implemented within the next ten years would require an increase in expected electrical generation needs of 0.5 per cent over the present predictions for the steel industry. This additional requirement would account for 0.8 per cent of the total industrial use of electricity by the year 1987.

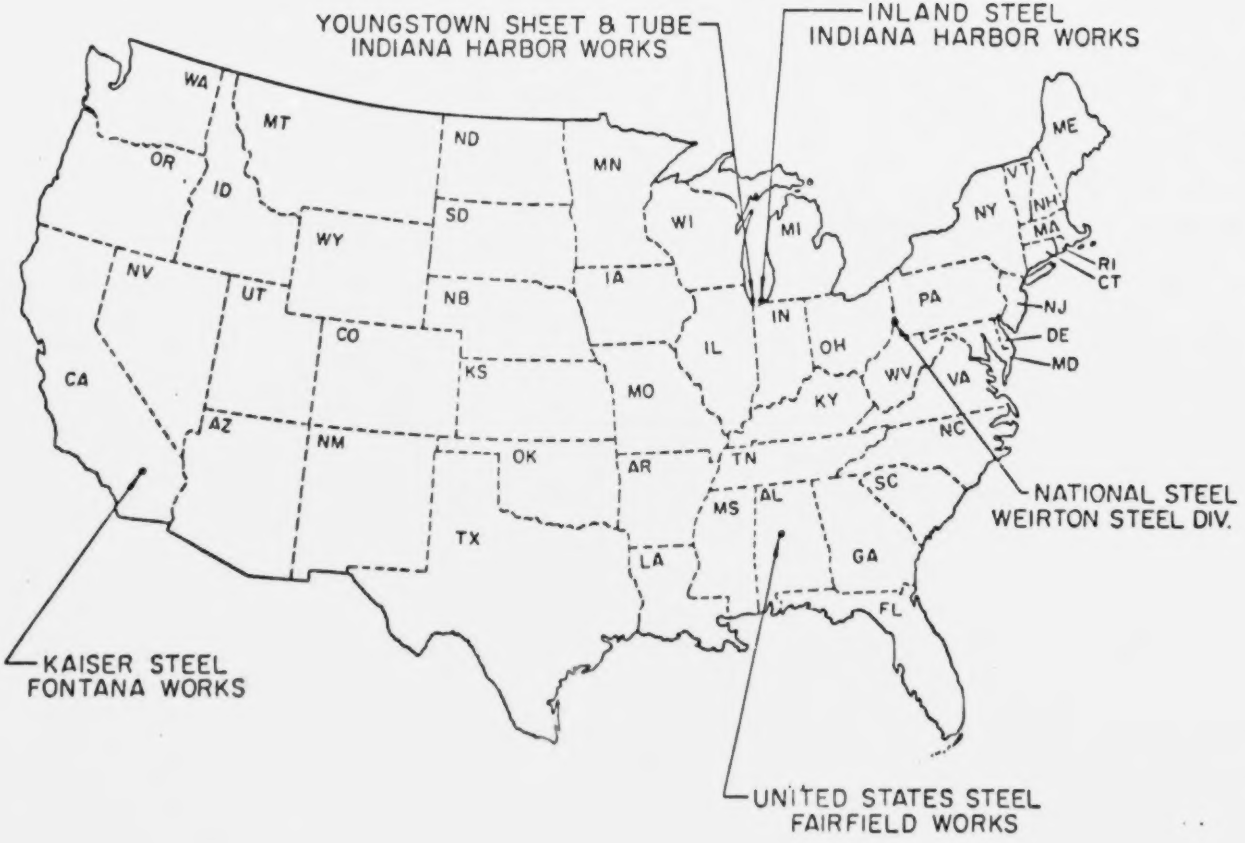
Water Loss

Water will be lost due to evaporation under the requirements of total recycle. The loss to the atmosphere of the additional amount of water may have detrimental effects on the meteorology of nearby areas.

SUGGESTED RESEARCH

In the formulation of the various possible means of attaining the BAT and total recycle, wastewater treatment processes have been shown which have not been tested on a full scale basis and, in some cases, smaller scale tests have not been performed. Use of these processes, however, was necessary because existing proven technology within the steel industry to attain this goal does not exist for total recycle and, although it is available for BAT in the main, certain areas such as the tin plating process do not possess this proven technology.

Whenever technology is suggested for application to an industry where it has not been previously proven, there is great and justified concern expressed. These concerns are justified by the fact that industry cannot spend large amounts of money to build facilities which they feel may never operate successfully. It is, therefore, mandatory that research programs be initiated prior to any decision to impose the requirement of total recycle. Some areas of needed research are: multi-step biological treatment of by-product coke plant wastewaters, treatment of blast furnace gas washer system blowdown and treatment of wastewaters to remove dissolved solids. It is assumed that the zero discharge requirement for tinning operations will be changed in the present review of the guidelines. If this is not accomplished, research in this area will also be needed.


YOUNGSTOWN SHEET & TUBE
INDIANA HARBOR WORKS
INLAND STEEL
INDIANA HARBOR WORKS
NATIONAL STEEL
WEIRTON STEEL DIV.
UNITED STATES STEEL
FAIRFIELD WORKS
KAISER STEEL
FONTANA WORKS
WA
OR
CA
ID
NV
MT
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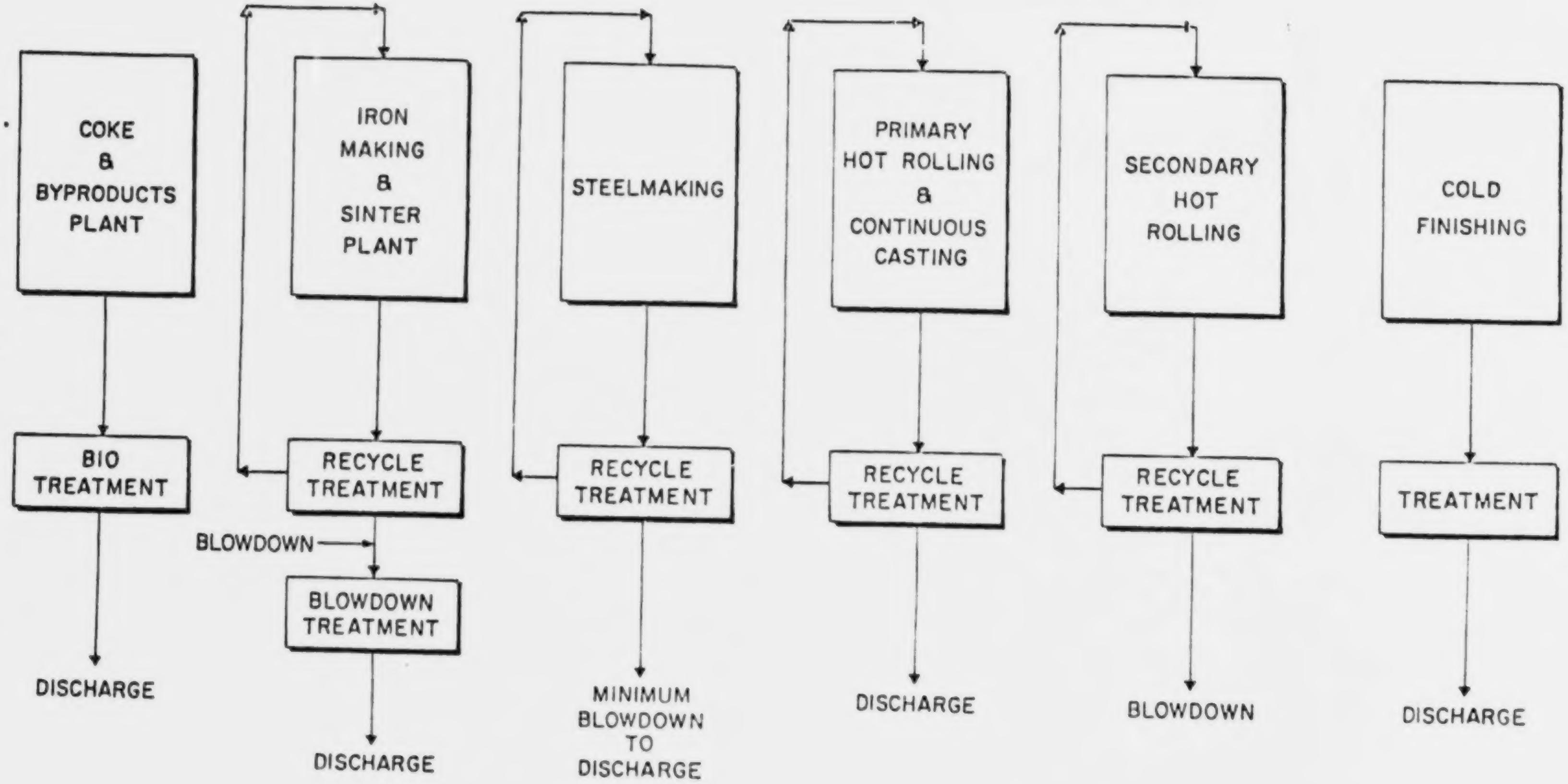
LOCATIONS OF SELECTED INTEGRATED PLANTS

Fig. I

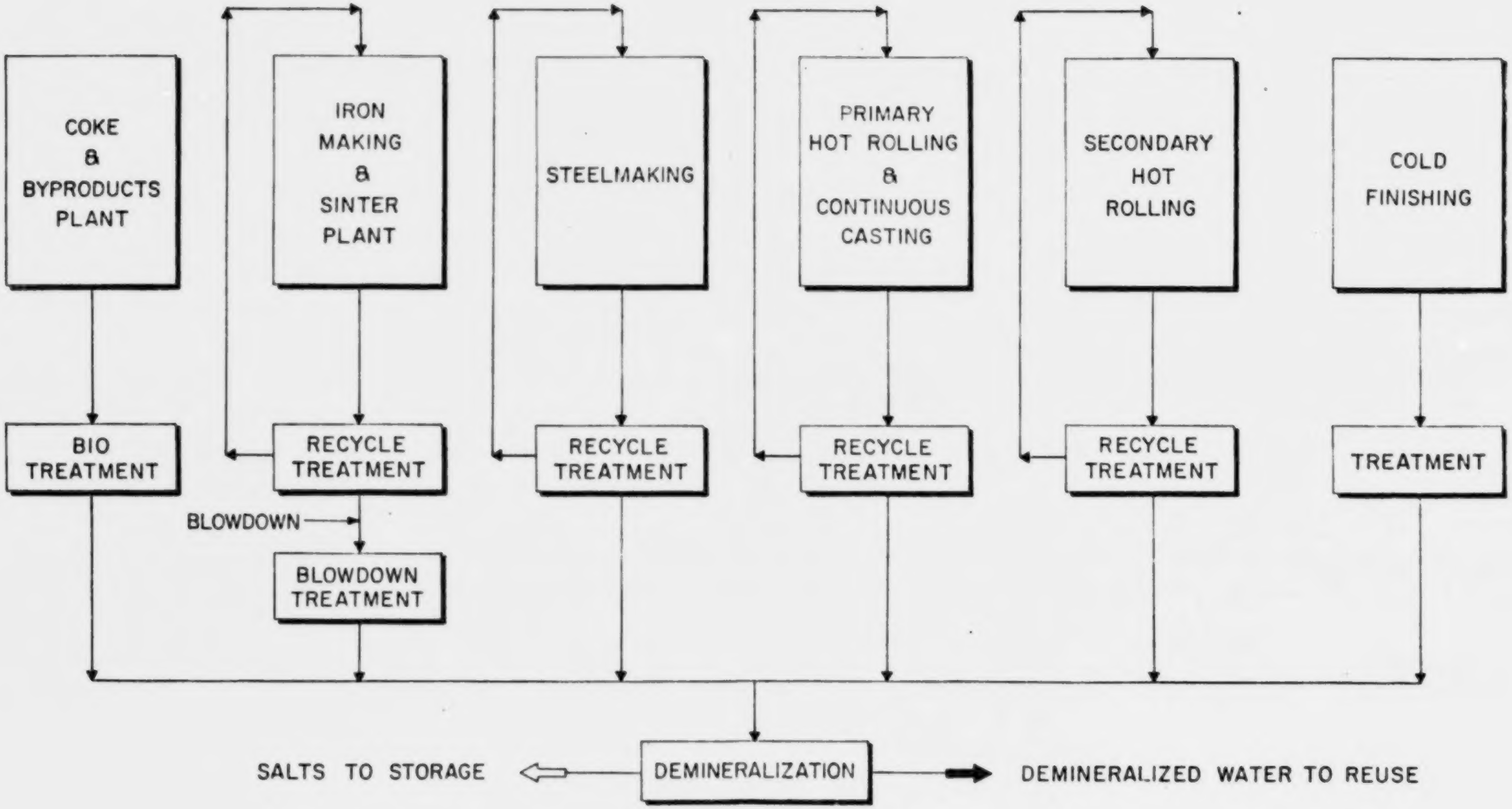

COKE & BYPRODUCTS PLANT
BIO TREATMENT
DISCHARGE
IRON MAKING & SINTER PLANT
RECYCLE TREATMENT
BLOWDOWN
BLOWDOWN TREATMENT
DISCHARGE
STEELMAKING
RECYCLE TREATMENT
MINIMUM BLOWDOWN TO DISCHARGE
PRIMARY HOT ROLLING & CONTINUOUS CASTING
RECYCLE TREATMENT
DISCHARGE
SECONDARY HOT ROLLING
RECYCLE TREATMENT
BLOWDOWN
COLD FINISHING
TREATMENT
DISCHARGE

TYPICAL INTEGRATED STEEL PLANT

RECOMMENDED SYSTEMS FOR BAT LIMITATIONS

(DOES NOT SHOW NON-CONTACT COOLING WATER)

FIG. 2


COKE
&
BYPRODUCTS
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IRON
MAKING
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SINTER
PLANT
STEELMAKING
PRIMARY
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CASTING
SECONDARY
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TREATMENT
BLOWDOWN
BLOWDOWN
TREATMENT
SALTS TO STORAGE
DEMINERALIZATION
DEMINERALIZED WATER TO REUSE

TYPICAL INTEGRATED STEEL PLANT

RECOMMENDED SYSTEMS FOR TOTAL RECYCLE

(DOES NOT SHOW NON - CONTACT COOLING WATER)

FIG. 3

TABLE I

DISSOLVED SOLIDS REMOVAL

	Pretreatment Costs ($\$ \times 10^6$)		Treatment Costs ($\$ \times 10^6$)		Evaporation Costs* ($\$ \times 10^6$)		Solids Disposal Costs** ($\$ \times 10^6$)		Total System Costs ($\$ \times 10^6$)		Annual Energy Requirements	
	Capital	Annual	Capital	Annual	Capital	Annual	Capital	Annual	Capital	Annual	$J \times 10^{13}$ ($kWh \times 10^6$)	$J \times 10^{15}$ ($BTU \times 10^{12}$)
Ion Exchange	1.15	0.25	14.0	8.78	12.18	18.99	-	17.6	27.33	45.62	12.24 (34)	7.635 (7.23)
Reverse Osmosis	9.95	1.83	10.1	2.63	19.12	29.87	-	10.2	39.17	44.53	18.97 (52.7)	12.776 (12.1)
Electrodialysis	9.95	1.83	9.0	3.08	15.48	23.53		8.45	34.43	36.89	11.41 (31.7)	10.18 (9.64)
Total Evaporation					73.29	103		40.8	73.29	143.8	9.4 (26.1)	511.104 (484)

* Includes cost of flue gas desulfurization.

** Assumption is that land would not be available on site and that solids would be hauled 5 miles off site.

Annual costs include amortization at 10 percent over 15 years plus operations and maintenance.

TABLE II

SUMMARY OF PLANT COSTS TO MEET BAT AND TOTAL RECYCLE

Plant	Phase	Capital Costs $	Annual Costs $	Plant Capacity kkg/yr (ton/yr)	Addl Annual Cost $/kkg(ton)
Kaiser-Fontana	BAT	-	-		-
	Total Recycle w/o NCCW	-	-	3,267,000 (3,600,000)	-
	Total Recycle w/ NCCW	17,717,000	9,762,000	-	2.99 (2.71)
Inland Steel Corp. - Indiana Harbor Works	BAT	36,300,000	18,823,000		1.91 (1.73)
	Total Recycle w/o NCCW	94,172,000	75,235,000	9,866,000 (10,877,000)	7.63 (6.92)
	Total Recycle w/ NCCW	162,079,000	139,875,000		14.18 (12.86)
National Steel - Weirton Steel Division	BAT	24,051,000	10,298,000		2.63 (2.39)
	Total Recycle w/o NCCW	120,633,000	125,595,000	3,912,000 (4,312,000)	32.11 (29.13)
	Total Recycle w/ NCCW	129,814,000	129,933,000		33.21 (30.13)
United States Steel - Fairfield Works	BAT	7,760,000	5,559,000		2.52 (2.28)
	Total Recycle w/o NCCW	-	-	2,208,000 (2,434,000)	-
	Total Recycle w/ NCCW	59,192,000	69,344,000		31.41 (28.49)
Youngstown Sheet & Tube - Indiana Harbor Works	BAT	19,580,000	23,648,000		3.95 (3.58)
	Total Recycle w/o NCCW	65,880,000	59,172,000	5,993,000 (6,606,000)	9.87 (8.96)
	Total Recycle w/ NCCW	74,350,000	64,571,000		10.77 (9.77)
Totals*	BAT*	79,931,000	52,769,000		2.67 (2.42)
	Total Recycle w/o NCCW	280,685,000	260,002,000	19,771,000 (21,795,000)	13.15 (11.93)
	Total Recycle w/ NCCW	366,243,000	334,379,000		16.91 (15.34)

* NOTES:
1. Costs shown for total recycle with and without non-contact cooling water include costs of BAT
2. *Totals do not include Kaiser Fontana and USSC-Fairfield.
3. NCCW is non-contact cooling water.

USE OF SPENT PICKLE LIQUOR TO REMOVE THE PHOSPHATES IN MUNICIPAL SEWAGE TREATMENT PLANTS

by

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ABSTRACT

Spent pickle liquor (a ferrous sulfate waste product) from Bethlehem Steel's Sparrows Point steel-pickling operations was tested as a source of iron for removing phosphorus from municipal wastewater at the City of Baltimore's 185 Mgd Back River Wastewater Treatment Plant and at the District of Columbia's 300 Mgd Blue Plains Sewage Treatment Plant. The study demonstrated that the pickle liquor is effective in reducing the total and soluble phosphorus concentrations in the final effluents from trickling filter systems and from both high-rate and conventional activated-sludge systems. Continuing and full-time use of the waste pickle liquor (WPL) at the two plants would be of mutual benefit. Bethlehem Steel Corporation would be able to minimize disposal problems, and the wastewater treatment plants would realize significant operating cost savings by using WPL rather than other treatment chemicals.

USE OF SPENT PICKLE LIQUOR TO REMOVE THE PHOSPHATES IN MUNICIPAL SEWAGE TREATMENT PLANTS

INTRODUCTION AND SUMMARY

Bethlehem Steel Corporation has a daily supply of about 100,000 gallons of waste pickle liquor (WPL) available at its Sparrows Point Plant, a large integrated steelmaking facility, with a production capacity of about 7,000,000 ingot tons of steel per year. The steel plant, located on the Patapsco River close to where it flows into the Chesapeake Bay, is about ten miles southeast of Baltimore, Maryland and 50 miles north of Washington, D. C.

The WPL, a dilute sulfuric acid solution which contains ferrous sulfate ($FeSO_4$), is spent acid from the continuous pickling baths in which steel products are cleaned. It contains about 5.5% ferrous iron and 9% free acidity on a weight basis and has a specific gravity of about 1.2 (weighs about 10 lb/gallon). The iron-rich liquor is chemically clean, i.e., it is low in heavy metals and suspended solids as compared with some of the other chemical additives commonly sold to sewage treatment plants for phosphorus removal and sludge conditioning.

Sparrows Point was interested in finding beneficial uses for all or part of the WPL rather than dealing with it merely as a waste disposal problem. To this end, Bethlehem approached Baltimore and Washington, D. C. with the proposal that the WPL be tested as an agent for phosphorus removal at their municipal sewage treatment plants. In cooperation with municipal and regulatory officials, Bethlehem planned extensive trials of the WPL as a phosphorus precipitant at the 185 $\bar{M}$gd Back River Wastewater Treatment Plant and the 300 $\bar{M}$gd Blue Plains Wastewater Treatment Plant. Trials run during a 3-1/2-month period in 1978 at the Baltimore plant and during the summer and fall months of 1979 at the D. C. plant proved the effectiveness of the proposed method of phosphorus removal:

- At Back River the total and soluble phosphorus contents of the activated sludge final effluent were reduced to less than 0.5 mg/l and 0.2 mg/l, respectively; the trickling-filter final effluent total and soluble phosphorus concentrations were reduced to 3.2 mg/l and to <1.0 mg/l, respectively.

- In high-rate activated sludge treatment at Blue Plains the final effluent total and soluble phosphorus concentrations were as low as 0.33 mg/l and 0.11 mg/l, respectively.

Trial results show that the addition of WPL did not significantly lower the pH of the final effluent from either sewage treatment plant. At Baltimore for every 5 mg/l of WPL iron tested, there was a decrease of about one-tenth of a pH unit; at Blue Plains, where ferric chloride was being replaced with equivalent WPL iron units, pH changes were negligible. Only about 1 gallon of WPL had to be added to every 5,000 gallons of sewage to obtain iron dosages of 10 mg/l, and there was sufficient alkalinity in the sewage to maintain final effluent pH levels around 7.

Subsequent to the successful test program at Back River, and through cooperative efforts among all concerned parties, the City of Baltimore formally approved a contract on August 16, 1979 for the use of 40,000 gpd of Sparrows Point pickle liquor at the Back River facility starting in early 1980. Bethlehem and Washington, D. C. officials are presently negotiating a contract for utilizing WPL at Blue Plains.

WPL TRIAL AT BACK RIVER WASTEWATER TREATMENT PLANT

The City of Baltimore's Back River Wastewater Treatment Plant has received considerable publicity during the past ten years because of environmental problems in Back River caused in part by phosphorus in the final effluent from the facility. Since the city was interested in developing near- and long-term methods which combined favorable economics and sound technology for upgrading the facility and minimizing phosphorus pollution of Back River, it was receptive to Bethlehem's recommendation for a cooperative study to determine the efficacy of using WPL in the Back River facility.

As a first step, the city agreed early in 1978 to assist Bethlehem conduct bench-scale tests to determine optimum ferrous iron dosage rates and injection locations for the WPL. According to this preliminary study, adding WPL to the primary effluent at 15 to 20 mg of ferrous iron per liter of sewage in conjunction with 0.2 mg/l of polyelectrolyte for solids coagulation would provide maximum removal of phosphorus and suspended solids in the full-scale facility. Guided by plant layout and results of this study, Bethlehem, the City of Baltimore and the Maryland Department of Natural Resources agreed upon a full-scale WPL demonstration.

Commencing in May 1978 the demonstration was conducted in four phases in terms of the ferrous iron concentration:

- 5 mg/l in May
- 10 mg/l in June
- 15 mg/l in July
- 20 mg/l in August

Sparrows Point committed over $300,000 to storage and injection facilities for WPL and polymer and to purchase polymer and pay trucking costs of the spent acid to Back River. Baltimore obtained a grant from the EPA for $70,000 for the additional operating and manpower costs the city was to incur during the trial.

The Back River Plant, Figure 1, is a biological treatment facility which handles an average of 185 Mgd of wastewater from Baltimore City, Baltimore County, and other bordering municipalities. The sewer collection system serves an industrial-residential area of about 140 square miles supporting a population of 1,385,000. The sewage contains about 6 to 10 mg of total phosphorus per liter of sewage and is moderately strong as far as biochemical oxygen demand (BOD), nitrogen and suspended solids are concerned.

Primary treatment facilities at the plant precede the biological treatment facilities. Primary treatment consists of mechanical screening, grit removal, and primary settling. After primary treatment the sewage undergoes biological treatment, final clarification, and chlorination. Biological treatment is divided between an older trickling filter system which handles about 135 M̄gd, and a newer activated-sludge treatment facility, which treats 50 M̄gd. The treated effluent is clarified in circular tanks following the activated-sludge system and in rectangular and circular humus tanks following the trickling filters. Solids retention times of about 3-1/2 days are usually maintained in the activated system. Average hydraulic retention time for this system is about six hours. All excess activated sludge is returned to gravity thickener tanks or to an inlet chamber along with humus-tank solids ahead of the grit chambers and primary clarifiers.

The Back River Plant discharges its treated effluents at two points: (a) 55-85 M̄gd to the head of Back River (outfall 001), a brackish tidal river adjacent to the facility, and (b) the remaining 100-130 M̄gd is discharged by gravity to the Sparrows Point facility (outfall 002) through about 6 miles of Bethlehem-owned pipelines. At Sparrows Point this effluent serves as multi-purpose industrial water in finishing mills and plant areas.

The treatment of the 185 M̄gd of sewage at Back River results in the daily generation of 300-400 wet tons (60 to 80 dry tons) of filtercake solids which are disposed of at a private landfill adjacent to Back River property. The solids-handling process consists of gravity sludge thickeners, high rate anaerobic digesters, elutriation tanks, and vacuum filters.

The rationale for Back River Plant expansion to meet future effluent limitations, such as for phosphorus, is being developed under a federally sponsored 201 Facilities Plan. The Back River effluent limitations for post-1981 have not been finalized by EPA or Maryland's Department of Natural Resources. However, Baltimore is aware that a phosphorus limitation of from 2.0 mg/l to perhaps as low as 0.2 mg/l may be imposed on the final effluent from the facility, depending on the technical and economic outcome of the 201 study.

During the 110-day plant trial, about 3.5 M̄ gallons of pickle liquor was injected under controlled rates into 20 billion gallons of sewage. An average truckload of WPL shipped from Sparrows Point during the trial contained 4,300 gallons, weighed 44,300 pounds, and averaged about 5.5% ferrous iron and 9% acidity by weight.

WPL delivered to the site was sampled routinely and analyzed for iron and acidity. The injection rate was dependent upon the analyzed iron concentration, the primary effluent flow, and the iron concentration being tested. The primary effluent flow was obtained from a totalizing meter near the injection site. The daily WPL use was determined from an integrating meter at the injection site along with a tabulation of shipping manifests and storage tank readings.

The WPL was pumped through a distribution manifold submerged in the primary effluent channel at rates required to attain 5 to 20 mg/l iron concentrations in the sewage going to biological treatment. This manifold was located immediately upstream of a second manifold through which air was being sparged for thorough mixing of the WPL and sewage. As primary effluent flows or the iron concentration changed, the WPL addition rate was varied manually by valve changes on the pressure side of the injection pumps.

Grab and composite samples, obtained from various locations in the treatment plant three times daily, were analyzed by Bethlehem Steel personnel and Back River laboratory personnel for pH, suspended solids, soluble and total iron, and soluble and total phosphorus. The grab-sampling locations analyzed by Bethlehem were: primary effluent pre-WPL injection, primary effluent post-WPL injection, activated-sludge final effluent, and final effluent from the trickling filter (humus tank). In addition to the grab samples, 24-hour composite samples were obtained by Back River personnel for analyses from various locations and were analyzed for pH, TSS, BOD, total nitrogen, orthophosphorus, total phosphorus, and iron.

During most weekend and holiday periods, supply problems developed at Sparrows Point because of WPL shortages in the 60,000-gallon storage tank. Pickling operations generally are shut down for these periods, and WPL consumption at Back River exceeded production. During these periods it was standard operating practice at Back River to reduce WPL addition rates until production at Sparrows Point increased. These supply problems resulted in lower iron concentrations, especially for July and August weekends and holidays when large volumes of spent acid were utilized to obtain iron concentrations of 15 and 20 mg/l. Daily WPL injection rates for the 3-1/2 months of the trial averaged 18,000, 30,000, 36,000, and 49,000 gpd for May, June, July, and August, respectively. The lowest daily addition rate was 10,500 gallons on May 28, 1978, and the highest rate was 70,200 gallons on August 15, 1978. Table I lists the average monthly WPL injection rates; and Table II summarizes major operational changes during each period.

Results At Back River Sewage Treatment Plant

Phosphorus Removal. Figures 2 and 3 present monthly average total and soluble phosphorus concentrations for the period April through August 1978 for the activated-sludge and trickling-filter systems. The data clearly show the steady drop in effluent phosphorus concentrations as iron concentrations in the system increased stepwise from 5 up to 20 mg/l.

The average monthly total phosphorus concentrations in the activated-sludge effluent during 1977 varied from a low of 1.5 mg/l when only about 30 mgd of sewage was processed in the activated-sludge system, to a high of 3.5 mg/l in March of 1978 when about 50 mgd of sewage was processed. During 1977 the average total phosphorus concentration in the activated effluent was 2.2 mg/l.

Figure 2 shows the effect on the activated sludge effluent of adding various levels of ferrous iron to the primary effluent. Total phosphorus was reduced from 2.1 mg/l in April 1978 down to a 0.85 mg/l for May, representing, respectively, the pre-trial month when no WPL was added and the first month of the trial when only 5 mg/l iron was added to the system. The average total phosphorus concentrations of the activated effluent for June, July, and August, the 10, 15, and 20 mg/l ferrous iron addition periods, fell to 0.78, 0.50, and 0.47 mg/l, respectively. The hydraulic feed to the activated system was maintained at 45 to 50 Mgd for the 3-1/2 month trial.

The soluble phosphorus concentrations of the activated-sludge effluent were reduced from a 1.24 mg/l for the pre-trial April period to 0.7, 0.4, 0.18, and 0.14 mg/l at respective monthly iron addition rates of 5, 10, 15, and 20 mg/l.

The total phosphorus concentration of the trickling-filter final effluent averaged 7.1 mg/l during 1977 when no ferrous iron was added to the system. As shown in Figure 3, WPL ferrous iron addition to the trickling-filter system significantly reduced this level with increasing additions of the iron. The trickling-filter phosphorus data indicate that with more efficient capture of suspended solids in the humus tanks, total effluent phosphorus concentrations could be still further reduced because almost all of the phosphorus exiting the final trickling-filter clarifiers during the latter stages of the WPL trial was particulate phosphorus.

The total phosphorus effluent concentration was reduced in the trickling-filter facility from 7.3 mg/l at the start of the trial to successive monthly averages of 5.8, 4.3, 3.9 and 3.2 mg/l at ferrous iron additions of, respectively, 5, 10, 15 and 20 mg/l. The soluble phosphorus levels of the trickling-filter effluent were reduced even more significantly than the total phosphorus concentrations. With increasing iron additions, the soluble phosphorus level was reduced from 4.8 mg/l at the start down to 0.9 mg/l at the 20 mg/l iron dose.

Biochemical Oxygen Demand, Five-Day Demand (BOD_5). Figure 4 presents monthly average BOD_5 final effluent concentrations for both the activated-sludge and trickling-filter systems. The BOD_5 concentrations for 1977 averaged 13 and 45 mg/l, respectively. As shown in Figure 4, BOD_5 removal for the activated-sludge system improved as the ferrous iron addition levels were increased from 5 to 20 mg/l during the 3-1/2 months. The BOD_5 average during the 20 mg/l iron addition was less than 5 mg/l. While it appears that iron addition did improve BOD_5 removal in the trickling-filter system, the improvement is not as obvious as that in the activated-sludge system.

Figure 4 shows that the effluent BOD_5 concentration of the trickling-filter system remained fairly constant, averaging between 25 and 35 mg/l during the study. The lowest BOD_5 average of 25 mg/l occurred during the 20 mg/l iron addition and was the lowest monthly average in the two years. Some of this apparent improvement in BOD_5 removal during 1978 may be attributed to the decreased load on the trickling filters as a result of the start-up of a new 25 to 30 Mgd activated-sludge facility in January 1978.

Soluble Iron. Figures 5 and 6 give the average monthly soluble-iron concentrations for April 1978 through August 1978. As shown in Figure 5, the soluble iron levels in the activated-sludge effluent did not increase significantly throughout this period, being about 0.13 mg/l in April and decreasing to 0.11 mg/l during May when 5 mg/l iron was being added to the system. June and July showed soluble-iron increases to 0.17 and 0.25 mg/l, respectively, with a decrease to 0.14 mg/l for August when 20 mg/l of ferrous iron was being added.

Figure 6 shows that the soluble-iron concentration of the trickling-filter effluent increased from a low of 0.3 mg/l in April to 0.53 mg/l for May. The soluble-iron concentration increased to 0.6 mg/l during June and, with subsequent iron increases, rose to 0.76 and 0.9 mg/l for July and August.

While the soluble-iron concentration in the effluent from the humus tank increased during the trial, this concentration was not at a level that represents a serious problem for the environment. Considering the age of the trickling-filter bed, precipitation of better than 95% of the applied iron load was excellent. Baltimore will renovate the trickling filters if the city decides not to abandon them as a result of the 201 study.

Suspended Solids. Figure 7 presents monthly average suspended-solids concentrations in the final effluents during 1977 and 1978. These averages during 1977 for the effluents from the activated-sludge and trickling-filter humus tanks were 11 and 46 mg/l, respectively. As compared with the 1977-1978 background periods, there was a slight improvement in suspended-solids removal for the activated-sludge system, but the performance of the humus tanks declined. Because of various plant conditions related to suspended solids at the time of the trial, it is difficult to determine the direct relationship between ferrous iron addition and the concentrations of effluent suspended solids in the humus tanks. The suspended solids of the trickling-filter effluent for April 1978, (the pre-trial background month) was 60 mg/l. The average for the month of May shows an increase to 87 mg/l followed by decreases in June, July and August. The August average was 68 mg/l, i.e., 8 mg/l above the April background period.

The Back River Plant experiences sludge-thickening and sludge-handling problems that become acute during spring and summer months, but less severe during cooler months. These problems could result from increases in sewage temperature, and the concomitant increased biological activity can impair the settleability of the sludge by making the solids more buoyant as gas is produced. During such periods, solids build up within the system. With an increased load of poorly settling solids, some of which are colloidal, being returned to the primary settlers as recycle, primary performance deteriorates and this increases the suspended-solids load on the biological processes. The result, generally, is that higher suspended-solids levels are discharged from the humus tanks but not necessarily from the activated-sludge system. Since this condition was experienced at just the time when the WPL trial was started in May, it was not possible to document any relation between ferrous iron addition and the amount of suspended solids in the humus tanks.

During the trial, the addition of WPL did result in the production of additional sludge. Baltimore is installing four additional vacuum filters, which should be operational in 1980 and will help remove solids.

Operating data obtained from Back River show that the precipitated WPL iron solids did have a beneficial effect on sludge-handling processes. Tables III and IV present performance and cost data for sludge conditioning and disposal. Sludge-conditioning costs per dry ton of sludge handled during the trial were significantly reduced as compared with comparable costs in the background period. Average conditioning cost for the 16-month pre-WPL period was $8.60/dry ton of sludge handled in contrast with $6.28 during the trial.

Another benefit of the higher concentration of iron in the sludge was a significant improvement in vacuum filtration. Monthly averages for the filtercake percent solids in the 16-month pre-WPL period were 18.9% as compared with 20.3% for the period of the trial. The percent solids in the filtercake, which did not reach 20% during any of the background months, increased to 20.0, 20.6 and 21.1% in June, July and August, respectively.

The vacuum-filter yields also increased significantly during the trial, being as high as 5.7 lb of filtercake/sq ft of filter area/operating hour. The monthly averages (Table IV) for the pre-WPL period averaged only 4.0 as compared with 5.1 lb of filtercake/sq ft of filter area/operating hour.

WPL TRIAL AT BLUE PLAINS WASTEWATER TREATMENT PLANT

The Blue Plains Sewage Treatment Plant in Washington, D. C. handles an average of 300 Mgd of medium-strength sewage from primarily residential and office areas. The facility, located on 150 acres along the Potomac River near the southernmost end of the District of Columbia, serves an area of 725 square miles with a population of about 2,200,000. Less than half the sewage handled in the Blue Plains system originates in the District of Columbia, about 50% comes from Maryland and 6% comes from Virginia.

The Blue Plains Plant, (Figure 8) consists of primary treatment facilities, i.e., bar screens, aerated grit chambers and circular primary sedimentation tanks, as well as biological treatment facilities. The latter consist of six four-pass rectangular aeration tanks providing about 3.5 $\bar{M}$ cubic feet of aeration volume. Sludge ages of about one day are usually maintained in the activated-sludge system. Hydraulic retention time for aeration averages two hours. Aeration equipment includes submerged diffused-air aerators operated in conjunction with centrifugal blowers. Dissolved oxygen levels of at least 2.0 mg/l are maintained during biological treatment.

Floc formed in biological treatment by the oxidation of carbonaceous materials and by the agglomeration of colloidal sewage matter is settled in rectangular clarifiers. The practice at Blue Plains has been to add, prior to final clarification, ferric chloride and polymer for phosphorus removal and solids coagulation. Ferric chloride has generally been added at dosages of 15-21 mg/l of ferric chloride (5-7 mg/l as iron). The ferric chloride, purchased from an outside company, costs Blue Plains about 22 cents/lb of iron. The chemical has a specific gravity of 1.4 (weighs about 11.6 lb/gal) and contains 8.5-10% ferric iron by weight. It is added to the aeration basin effluent in a well-mixed compartment positioned after the basins but ahead of the final clarifiers. To strengthen the iron floc an anionic polyelectrolyte, generally at a dose of 0.3 mg/l, is added after iron addition but ahead of final clarification.

Excess biological and chemical solids from activated-sludge treatment are wasted, i.e., removed, from clarifier underflows to air-flotation or gravity thickeners. After thickening the waste activated sludge is blended with gravity-thickened primary sludge and split into two streams. The major portion of the sludge is vacuum filtered as is. The remainder is digested and elutriated before dewatering. Prior to vacuum filtration the sludge is conditioned with lime and/or ferric chloride and/or polyelectrolyte.

Secondary effluent is chlorinated and then discharged to the Potomac River.

In recent years more than $400,000,000 has been spent on expansion of the plant. The major construction projects under way are facilities for nitrification and mixed-media filtration. Air-flotation thickeners and vacuum filters in the new solids processing building have been in service for about a year now.

The nitrification facility will be on line by 1980, and the mixed-media filtration should be operational by 1981. The addition of these advanced wastewater treatment facilities will result in an estimated daily generation of 400 wet tons (80 dry tons) of additional sludge which will increase the sludge production rate to about 2000 wet tons/day (400 dry tons/day).

A sludge/wood chip composting program at Blue Plains is handling about 20% of the sludge production, and the plan is to sell the composted mixture for agricultural purposes. The remaining 80% of the sludge produced, about 1,000 tons/day, is trucked to approved disposal sites in Maryland, where the material is trenched and covered in landfills by private contractors.

There are two activated-sludge aeration basins on the west side of the Blue Plains facility and four on the east side. To provide maximum aeration time for ferrous oxidation, all WPL during the trial was added to the head end of aeration basin 1 or 2 on the west side. The second aeration basin was used for control purposes, usually at a ferric iron dose equivalent to the ferrous iron dose that was being added in the other basin. Iron concentrations of 5, 7, and 10 mg/l were tested in detail during the May through August periods in 1979. Bethlehem Steel Corp. test work on-going through mid-October is expected to be completed by mid-November 1979.

Table V compares the WPL and ferric chloride data. During both the background and trial periods covered, 0.3 mg/l of polymer helped promote suspended-solids coagulation.

During April and May, pre-WPL trial data were collected. The primary effluent for the activated systems on the west side averaged 4.8 mg/l total phosphorus, 2.9 mg/l soluble phosphorus, and 81 mg/l total suspended solids. The final effluent from the odd and even final clarifiers, when 5 and 7 mg/l ferric iron were added to the system, averaged 1.4 mg/l total phosphorus, 0.7 mg/l soluble phosphorus, and 22 mg/l total suspended solids.

May 8 through May 20, 1979, ferrous and ferric iron dosages of 5 mg/l were tried in the two west-side activated-sludge systems and compared. WPL was added to aeration basin 1, and ferric chloride was added to basin 2. Total phosphorus concentrations in the final effluent were the same for both materials, 1.6 mg/l, but the soluble phosphorus concentration was better for the WPL-treated basin, i.e., 0.38 mg/l as compared with 0.58 mg/l for the basin treated with ferric chloride.

For the 7 mg/l iron addition period, total phosphorus concentrations in the final effluent averaged 1.06 mg/l for the ferrous iron side and 0.88 mg/l for the ferric iron side. However, soluble phosphorus concentrations were 0.22 mg/l for the ferrous iron side and 0.26 mg/l for the ferric iron side. The total suspended-solids averages were 24 mg/l and 23 mg/l, respectively.

There were two 10 mg/l ferrous iron periods, one in July when ferrous iron was added to aeration basin 2, and the second in August when the ferrous iron was added to aeration basin 1. For total phosphorus and suspended solids, removal by ferrous iron during the first 10 mg/l iron addition period (July) was not as good as that during the August period (Table III). Although there are some possible explanations for the poorer period, the important point is that the July data are not typical when viewed against the performance of the various periods to date.

For the August period, final-effluent total and soluble phosphorus concentrations averaged 0.33 mg/l and 0.11 mg/l for the ferrous iron addition, and 0.39 mg/l and 0.13 mg/l for the ferric chloride addition. Total suspended-solids concentrations in the final effluent were also less for the ferrous iron-treated side, i.e., 6 mg/l as compared with 9 mg/l for the ferric chloride-treated side.

Comparison of the performance of the ferrous iron dose of 6.7 mg/l with that by a 7.8 mg/l ferric iron dose for the August 21-31 period (the last reported in Table V) shows that on an iron-equivalent basis (lb of iron added/lb of P removed) the ferrous iron outperformed the ferric iron.

SUMMARY OF RESULTS

1. Back River Wastewater Treatment Plant, trickling-filter and activated-sludge systems

- Total phosphorus content of the activated-sludge effluent was reduced to less than 0.5 mg/l of phosphorus in the final effluent. Soluble phosphorus concentrations were reduced to less than 0.2 mg/l.

- Total phosphorus content of the trickling-filter effluent was reduced to 3.2 mg/l of phosphorus in the final effluent. Soluble phosphorus was reduced to less than 1 mg/l.

- The biochemical oxygen demand (BOD_5) of final effluents was reduced to the lowest levels in recent years. BOD_5 removal was over 90%.

- Chlorine demand of the final effluent was reduced.

- Sludge characteristics were improved, resulting in a higher percent solids in the filtercake. Percent solids averaged 18.9% for the 16 months preceding WPL addition and 20.3% for the WPL trial.

- Vacuum-filter yields were improved. Filter yields for the background period averaged 4.0 lb of filtercake/sq ft of filter area/operating hour as compared with 5.1 lb for the trial.

- Polymer demand for sludge conditioning decreased, thus reducing operating costs by $2.30/dry ton of sludge handled.

2. Blue Plains Wastewater Treatment Plant, high-rate activated-sludge system

- WPL ferrous iron at a 10 mg/l iron addition rate reduced the total and soluble phosphorus concentrations in the final effluent to an average of 0.33 and 0.11 mg/l, respectively, during the August trial period.

- When oxidized to ferric iron in the aeration basins, ferrous iron was an effective coagulant.

CONCLUSIONS AND RECOMMENDATIONS

Plant trials at the Back River and Blue Plains Sewage Treatment Plants demonstrated the effectiveness of waste pickle liquor for complexing and removing phosphates at both plants, and at Back River where chemicals are not used in biological treatment, the waste pickle liquor improved the coagulation and filtration of solids. Thus, it has been shown that steelplant waste pickle liquor can accomplish those improvements in municipal wastewater treatment that have traditionally been realized by the use of other, comparatively high-priced chemicals. It is therefore evident that the use of waste pickle liquor can be mutually beneficial -- a waste material is utilized that would otherwise require some sort of treatment and disposal at steel plants, and municipalities are offered the opportunity to minimize treatment costs.

The test programs discussed in this report exemplify commendable government/industry cooperation to benefit the public as a whole, as well as a steel corporation and two municipalities. We recommend that such cooperation should continue and that the EPA should encourage municipalities to investigate and utilize this treatment practice.

TABLE I. BACK RIVER WASTEWATER TREATMENT PLANT AVERAGE WPL INJECTION RATES

DATE 1978	AMOUNT GAL/DAY
MAY	18,000
JUNE	30,000
JULY	36,000
AUGUST	49,000

TABLE II. BACK RIVER WPL TRIAL SUMMARY OF OPERATIONAL CHANGES

Date	
May 1, 1978	WPL trial began at 5 mg/l ferrous iron addition.
June 1	Iron addition was increased to 7.5 mg/l.
June 6	Iron addition was increased to 10 mg/l.
June 16	WPL storage tank ruptured at 12 noon. WPL off.
June 17	Iron addition was resumed at 10 mg/l.
June 19	Polymer was discontinued at activated-sludge clarifier influent.
July 1	Iron addition was reduced to 2.5 mg/l for part of the day.
July 2	Iron addition was increased to 5 mg/l.
July 3	Iron addition was increased to 10 mg/l.
July 4	Iron addition was reduced to 5 mg/l.
July 5	Polymer was discontinued in the humus-tank influent.
July 9	Iron addition was increased to 12.5 mg/l.
July 13	Iron addition was increased to 15 mg/l.
August 6	Iron addition was reduced to 5 mg/l.
August 7	Iron addition was increased to 20 mg/l.
August 18	WPL trial terminated in the afternoon.

TABLE III. BACK RIVER SLUDGE CONDITIONING AND DISPOSAL COSTS

PRE-WPL PERIOD

Month	Elutriation Polymer lb/dry ton	Elutriation Polymer $/dry ton	Vacuum Filter Polymer lb/dry ton	Vacuum Filter Polymer $/dry ton	Conditioning Cost $/dry ton	Disposal Cost $/dry ton	Total Cost $/dry ton
January 1977	5.1	2.26	63.9	5.65	7.91	-	-
February	5.5	2.40	66.6	5.88	8.28	-	-
March	6.3	2.77	78.8	6.90	9.67	-	-
April	6.7	2.96	82.1	7.25	10.21	-	-
May	8.2	3.61	80.8	7.13	10.74	-	-
June	7.7	3.40	67.7	5.79	9.19	-	-
July	4.7	2.06	64.7	5.71	7.77	17.44	25.21
August	5.5	2.40	71.7	6.33	8.73	17.61	25.47
September	4.6	2.03	65.5	5.78	7.81	17.05	24.89
October	4.1	1.79	65.5	5.77	7.56	16.69	24.26
November	4.8	2.11	66.7	5.89	8.00	16.64	24.51
December	5.2	2.27	69.2	6.11	8.38	16.65	24.96
January 1978	5.1	2.22	85.3	7.53	9.75	16.80	26.49
February	5.3	2.35	69.4	6.13	8.48	16.56	25.03
March	3.3	1.60	66.5	5.87	7.47	16.53	23.86
April	3.9	1.70	66.9	5.91	7.61	16.51	24.12
PRE-WPL AVG.	5.4	2.40	70.7	6.23	8.60	16.85	24.88

WPL PERIOD

Month	Elutriation Polymer lb/dry ton	Elutriation Polymer $/dry ton	Vacuum Filter Polymer lb/dry ton	Vacuum Filter Polymer $/dry ton	Conditioning Cost $/dry ton	Disposal Cost $/dry ton	Total Cost $/dry ton
May	4.1	1.82	58.1	5.13	6.96	16.56	23.52
June	4.8	2.13	48.3	4.27	6.38	16.28	22.65
July	3.4	1.49	46.6	4.12	5.61	15.80	21.41
August	3.2	1.38	54.0	4.77	6.16	15.38	21.53
WPL TEST AVG.	3.9	1.71	51.8	4.57	6.28	16.01	22.28

TABLE IV. BACK RIVER ELUTRIATION AND VACUUM FILTER DATA

PRE-WPL PERIOD

	Elutriation Sludge	Filtercake	Filter Operation	Filter Yield		
Month	% solids	% solids	hours/day	$lb/ft^2/hour$	dry tons/day	wet tons/day
January 1977	5.1	19.4	33.45	4.1	49.0	252
February	4.6	19.7	47.12	3.7	63.4	322
March	4.9	17.7	48.36	3.4	59.6	336
April	5.0	18.0	59.23	3.1	67.6	375
May	4.7	16.4	45.23	3.9	62.4	383
June	5.0	17.5	47.06	4.3	72.7	414
July	4.9	18.7	45.18	4.6	74.2	397
August	4.4	18.5	43.90	4.1	64.4	349
September	4.8	19.1	46.38	4.2	69.6	365
October	4.9	19.5	47.30	4.2	71.5	367
November	5.0	19.5	45.82	4.4	71.6	366
December	4.9	19.6	39.91	4.0	57.6	296
January 1978	5.7	19.4	42.74	3.4	52.0	262
February	5.0	19.6	40.10	3.8	54.3	276
March	5.1	19.7	42.58	4.2	66.4	337
April	5.1	19.6	43.61	4.6	75.85	384
PRE-WPL AVG.	4.9	18.9	44.88	4.0	64.5	343

WPL PERIOD

	Elutriation Sludge	Filtercake	Filter Operation	Filter Yield		
Month	% solids	% solids	hours/day	$lb/ft^2/hour$	dry tons/day	wet tons/day
May	4.8	19.6	43.61	4.1	69.3	353
June	5.2	20.0	49.46	5.0	84.7	425
July	5.3	20.6	44.4	5.7	90.3	439
August	6.1	21.1	45.38	5.5	90.0	440
WPL TEST AVG.	5.4	20.3	45.71	5.1	83.6	414

TABLE V. SUMMARY OF BLUE PLAINS WPL TRIAL

Operating Period		Phosphorus, mg/l			Total Suspended Solids, mg/l		
		Primary Effluent	Aeration Basin Effluent		Primary Effluent	Aeration Basin Effluent	
			WPL	$FeCl_3$		WPL	$FeCl_3$
Pre-WPL Trial			-	Basins 1 & 2		-	Basins 1 & 2
(4/1/79 to 5/7/79)	P_{total}	4.8	-	1.4	81	-	22
	$P_{soluble}$	2.9	-	0.6			
5 mg/l Iron Addition			Basin 1	Basin 2		Basin 1	Basin 2
(5/8/79 to 5/20/79)	P_{total}	5.0	1.6	1.6	98	39	37
	$P_{soluble}$	2.6	0.38	0.58			
7 mg/l Iron Addition			Basin 1	Basin 2		Basin 1	Basin 2
(5/22/79 to 6/4/79)	P_{total}	4.7	1.06	0.88	91	24	23
	$P_{soluble}$	2.4	0.22	0.26			
10 mg/l Iron Addition			Basin 2	Basin 1		Basin 2	Basin 1
(7/11/79 to 7/22/79)	P_{total}	4.5	1.31	0.48	94	36	12
	$P_{soluble}$	2.2	0.15	0.11			
10 mg/l Iron Addition			Basin 1	Basin 2		Basin 1	Basin 2
(8/6/79 to 8/15/79)	P_{total}	3.9	0.33	0.39	96	6	9
	$P_{soluble}$	1.6	0.11	0.13			
7.8 mg/l Fe^{+3} Addition Basin 1 6.7 mg/l Fe^{+2} Addition Basin 2 (8/21/79 to 8/31/79)			Basin 2	Basin 1		Basin 2	Basin 1
	P_{total}	6.4	0.65	0.59	89	18	15

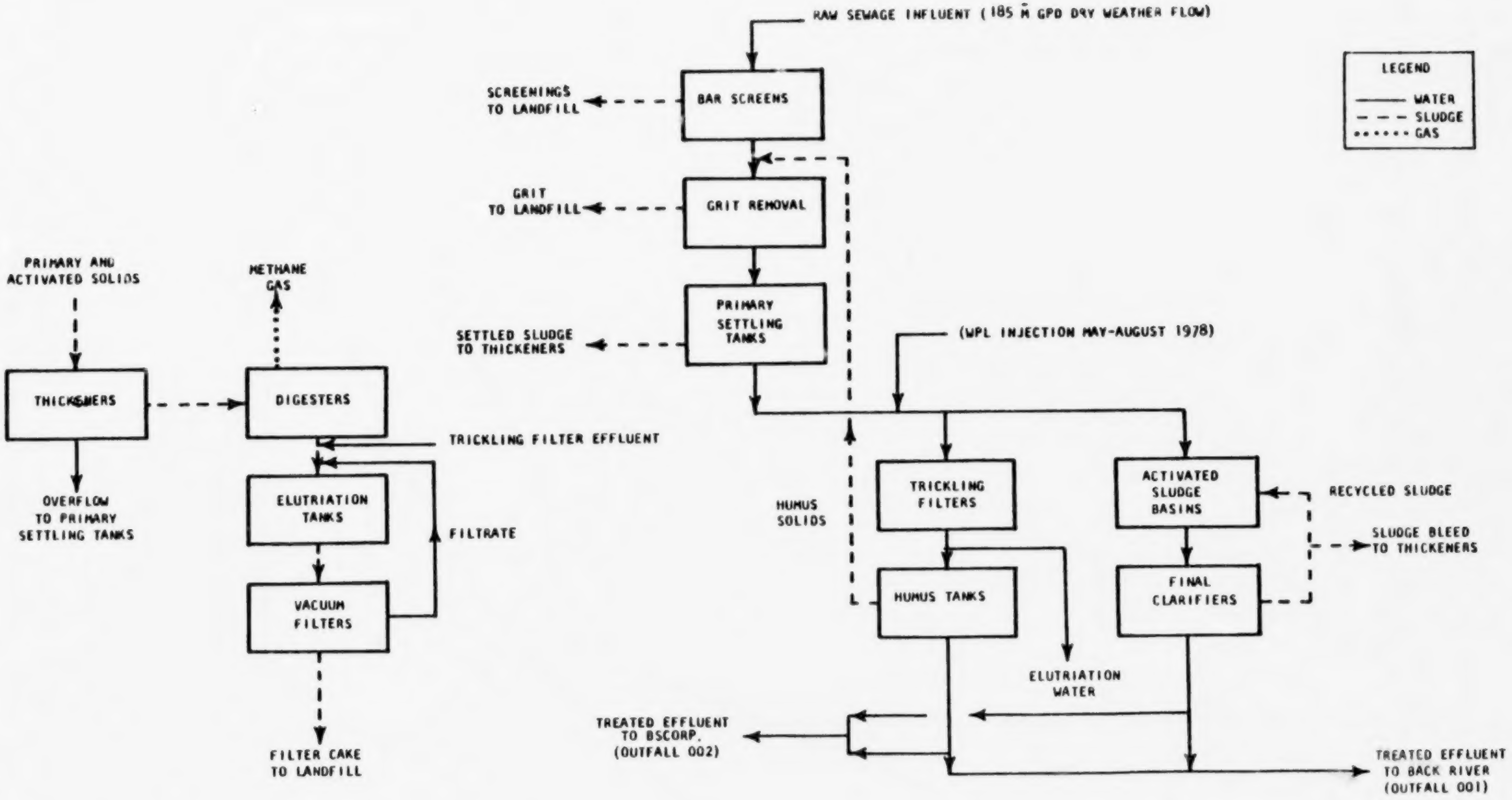
RAW SEWAGE INFLUENT (185 M̃ GPD DRY WEATHER FLOW)
LEGEND
WATER
SLUDGE
GAS
SCREENINGS TO LANDFILL
BAR SCREENS
GRIT TO LANDFILL
GRIT REMOVAL
SETTLED SLUDGE TO THICKENERS
PRIMARY SETTLING TANKS
(WPL INJECTION MAY-AUGUST 1978)
PRIMARY AND ACTIVATED SOLIDS
METHANE GAS
THICKENERS
DIGESTERS
TRICKLING FILTER EFFLUENT
ELUTRIATION TANKS
FILTRATE
VACUUM FILTERS
OVERFLOW TO PRIMARY SETTLING TANKS
FILTER CAKE TO LANDFILL
HUMUS SOLIDS
TRICKLING FILTERS
HUMUS TANKS
ACTIVATED SLUDGE BASINS
FINAL CLARIFIERS
RECYCLED SLUDGE
SLUDGE BLEED TO THICKENERS
ELUTRIATION WATER
TREATED EFFLUENT TO BSCORP. (OUTFALL 002)
TREATED EFFLUENT TO BACK RIVER (OUTFALL 001)

FIGURE 1. FLOW DIAGRAM OF BACK RIVER WASTEWATER TREATMENT PLANT

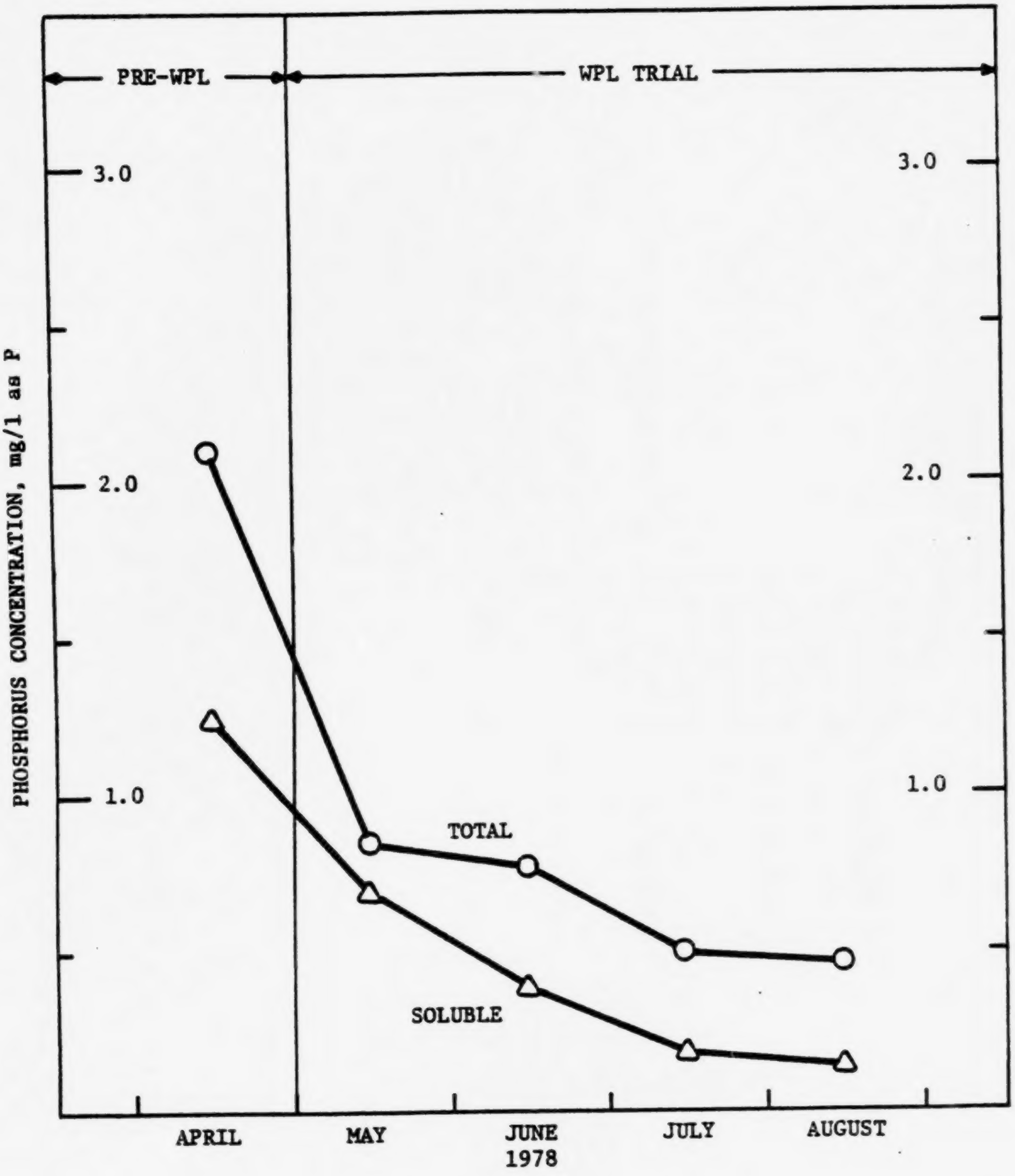

FIGURE 2. BACK RIVER WASTEWATER TREATMENT PLANT ACTIVATED SLUDGE EFFLUENT PHOSPHORUS

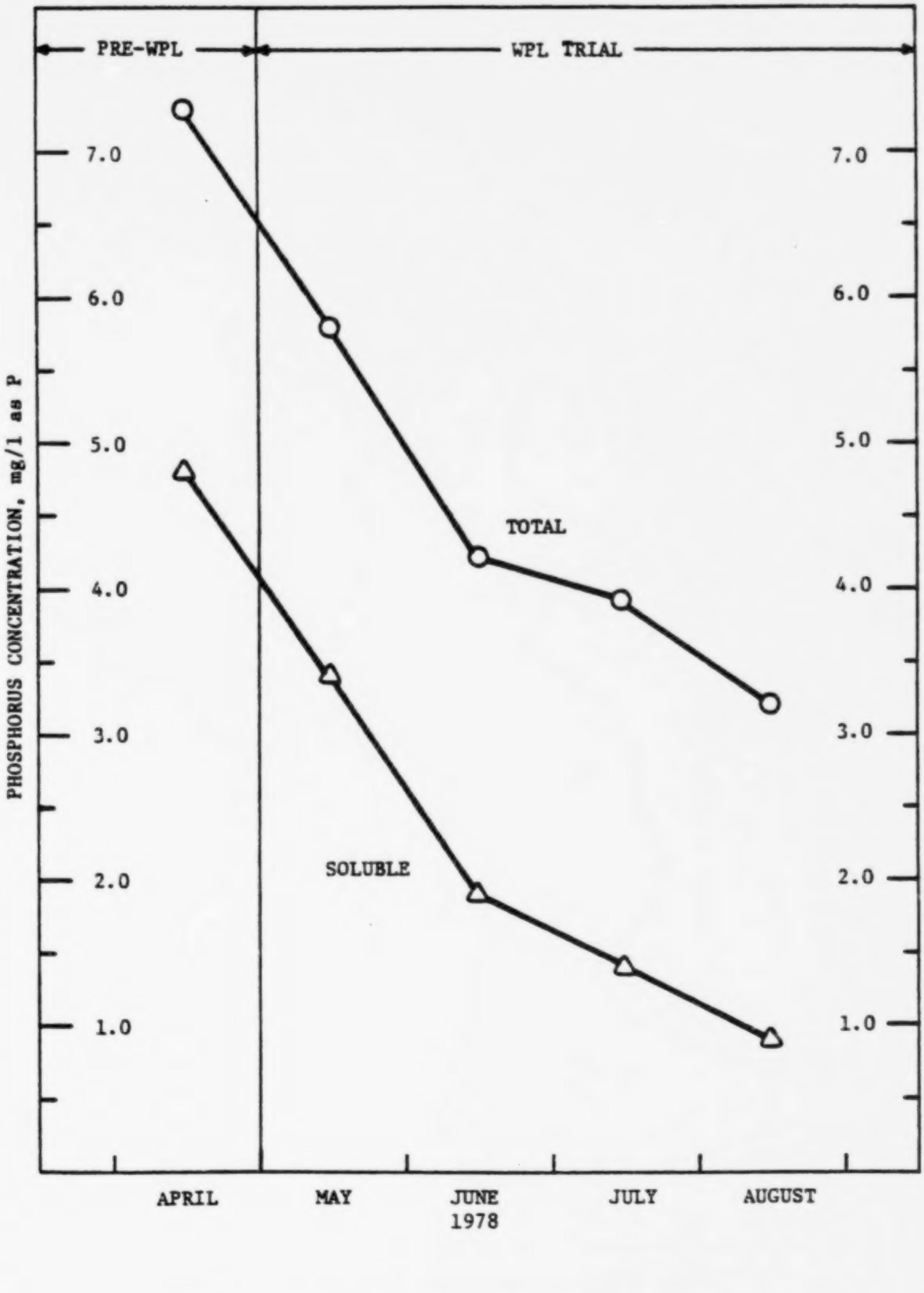

FIGURE 3. BACK RIVER WASTEWATER TREATMENT PLANT
TRICKLING FILTER FINAL EFFLUENT PHOSPHORUS

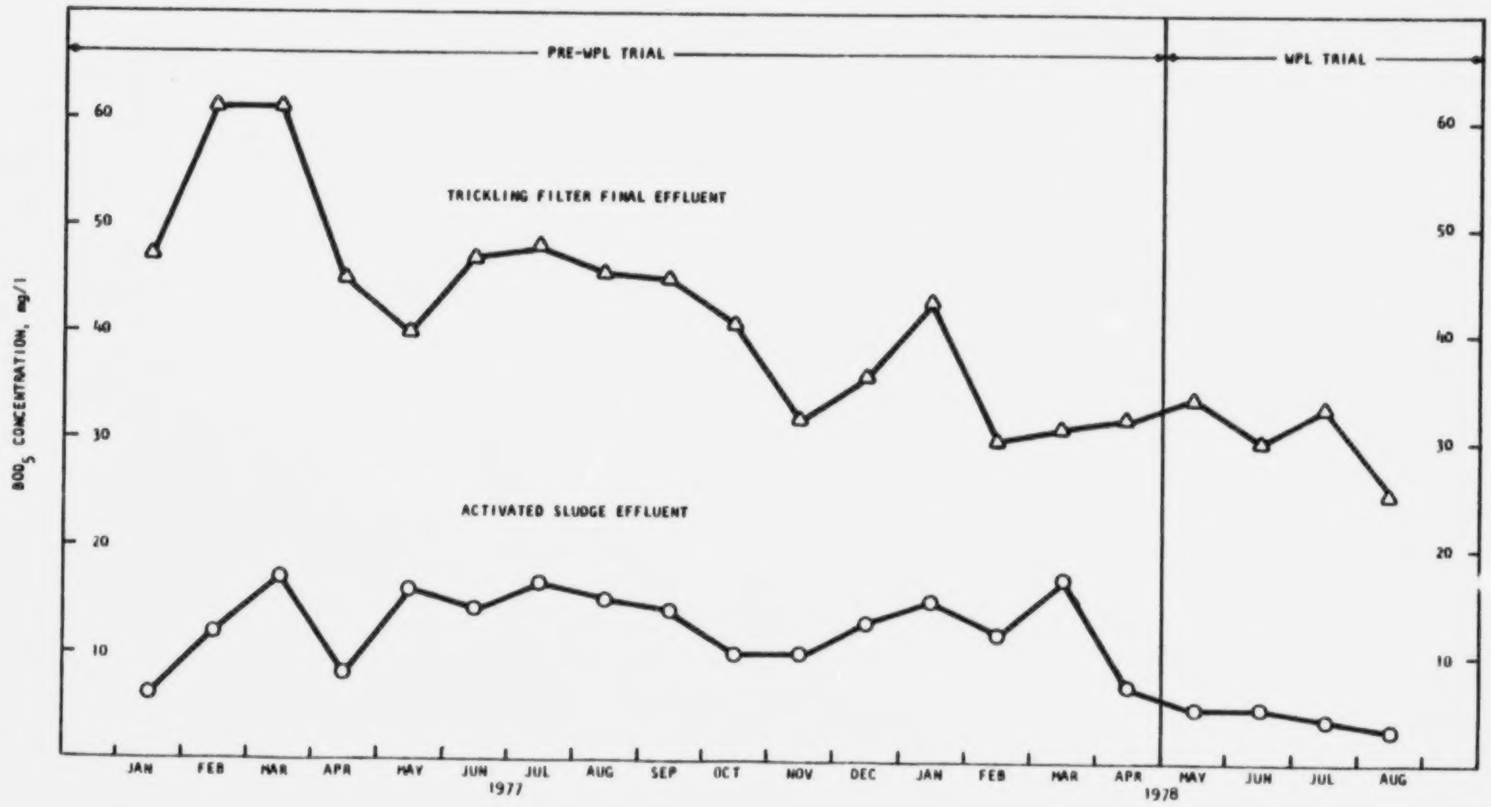

FIGURE 4. BACK RIVER WASTEWATER TREATMENT PLANT BOD_5 ANALYSES
MONTHLY AVERAGES OF DAILY COMPOSITE SAMPLES

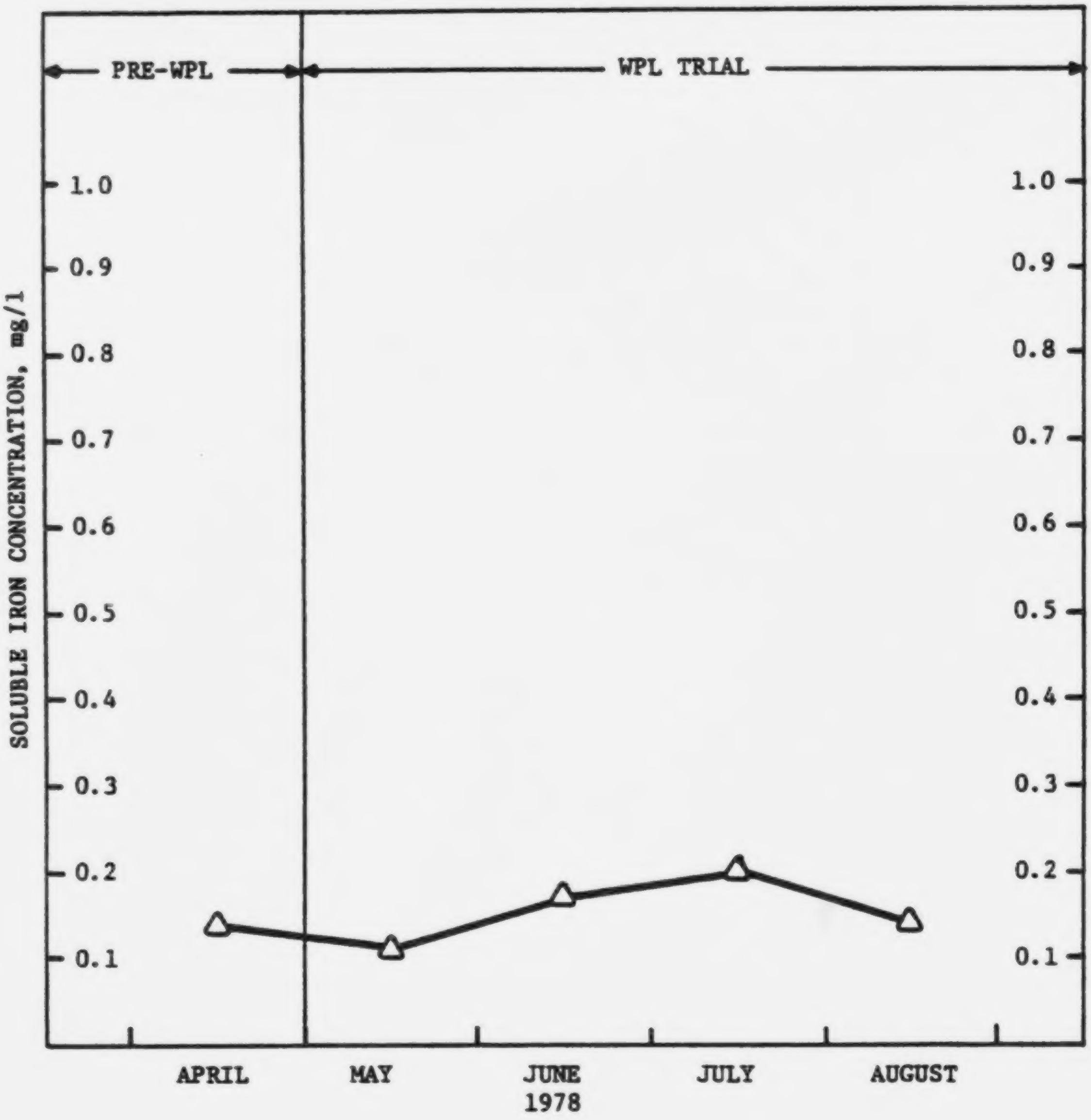

FIGURE 5. BACK RIVER WASTEWATER TREATMENT PLANT, SOLUBLE IRON IN ACTIVATED SLUDGE EFFLUENT

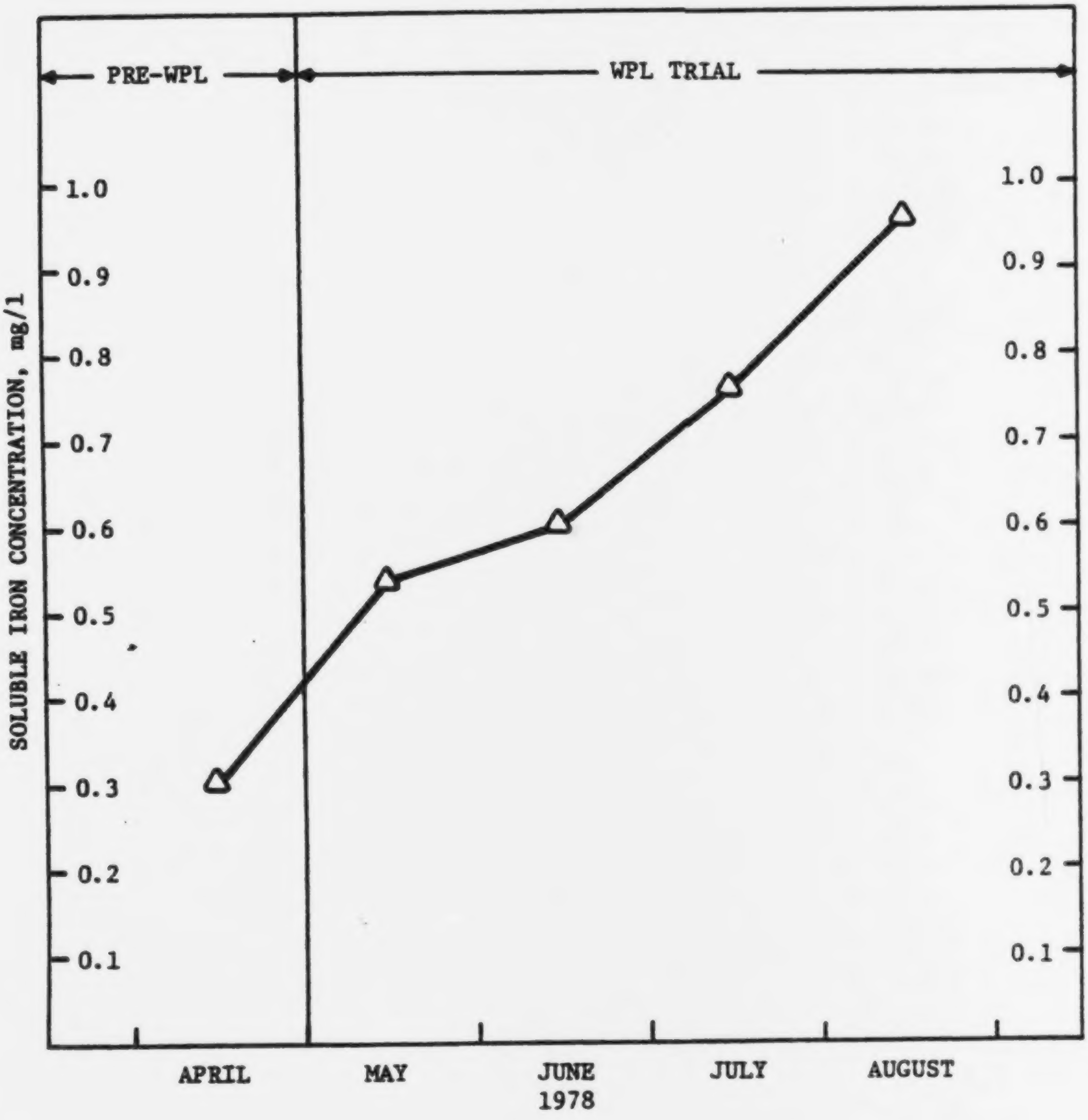

FIGURE 6. BACK RIVER WASTEWATER TREATMENT PLANT, SOLUBLE IRON IN TRICKLING FILTER EFFLUENT

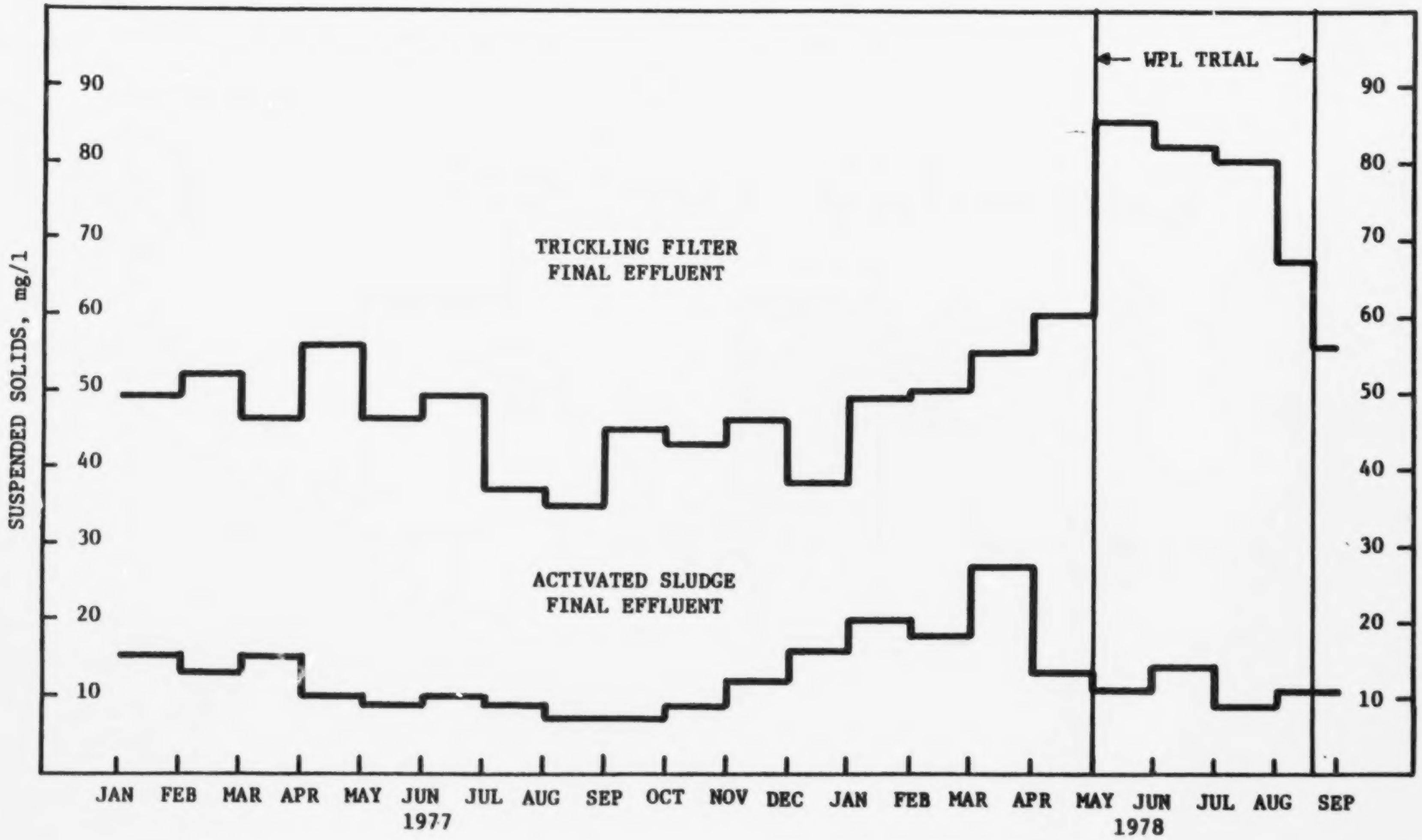

FIGURE 7. BACK RIVER WASTEWATER TREATMENT PLANT, EFFLUENT SUSPENDED SOLIDS

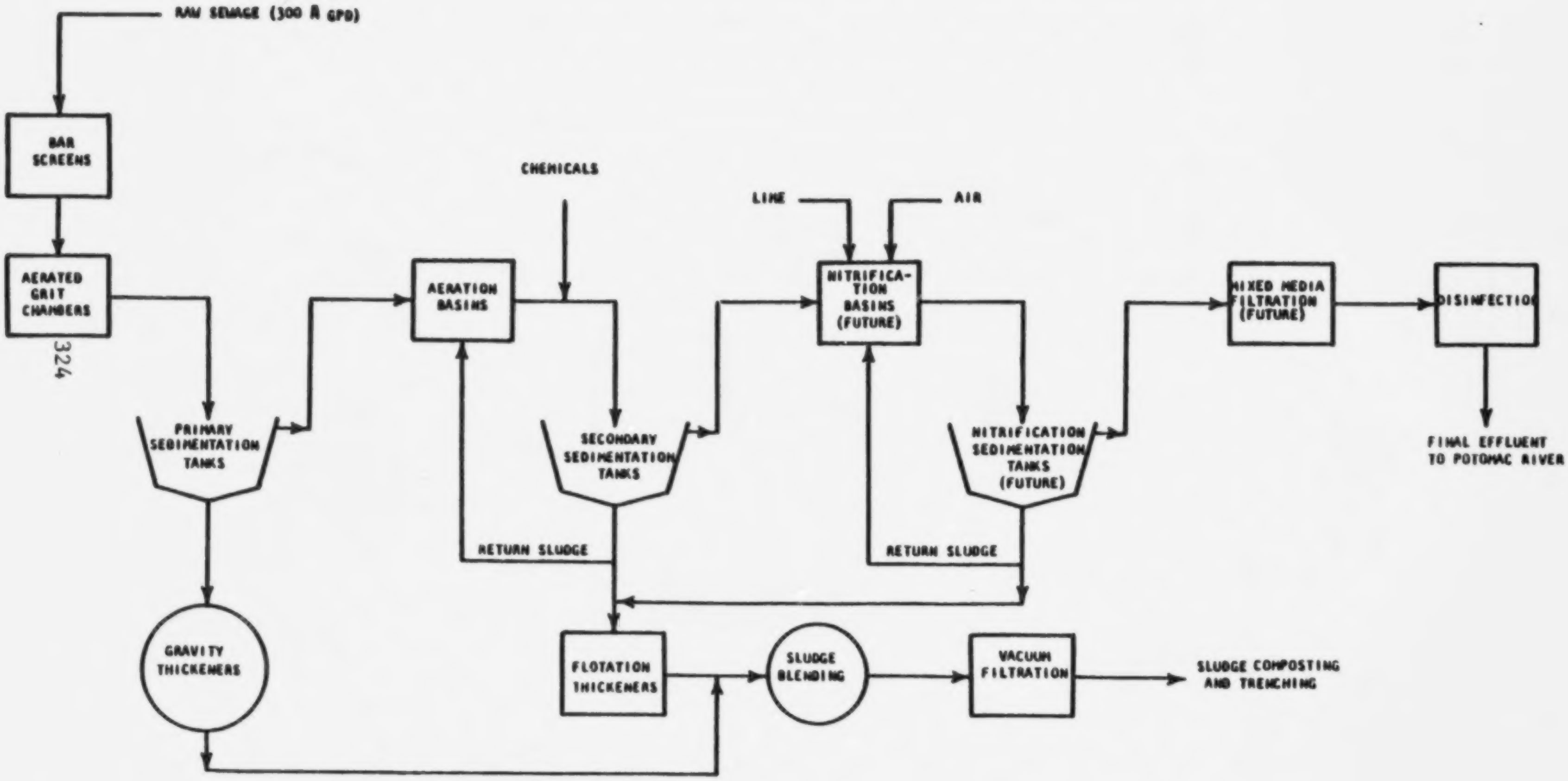
RAW SEWAGE (300 M GPD)
BAR SCREENS
AERATED GRIT CHAMBERS
PRIMARY SEDIMENTATION TANKS
GRAVITY THICKENERS
AERATION BASINS
CHEMICALS
SECONDARY SEDIMENTATION TANKS
RETURN SLUDGE
FLOTATION THICKENERS
SLUDGE BLENDING
LIME
AIR
NITRIFICATION BASINS (FUTURE)
NITRIFICATION SEDIMENTATION TANKS (FUTURE)
RETURN SLUDGE
VACUUM FILTRATION
SLUDGE COMPOSTING AND TRENCHING
MIXED MEDIA FILTRATION (FUTURE)
DISINFECTION
FINAL EFFLUENT TO POTOMAC RIVER

FIGURE 8. FLOW DIAGRAM OF BLUE PLAINS WASTEWATER TREATMENT PLANT

PHYSICAL-CHEMICAL TREATMENT OF STEEL PLANT WASTEWATERS USING MOBILE PILOT UNITS

by
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Rexnord Inc. Corporate R&D
Milwaukee, Wisconsin

Presented at the EPA Symposium on Iron and Steel Pollution Abatement Technology, Pick-Congress Hotel, Chicago, Illinois, October 31, 1979

"PHYSICAL-CHEMICAL TREATMENT OF STEEL PLANT WASTEWATERS USING MOBILE PILOT UNITS"

Richard Osantowski
Anthony Geinopolos
Environmental Research Center
Rexnord Inc.
Milwaukee, Wisconsin 53214

In-depth pilot scale evaluations investigating the applicability of advanced waste treatment methods for upgrading steel mill wastewaters to Best Available Technology Economically Achievable (BATEA) levels, which were proposed in 1974*, were performed. The wastewater tested was a Blast Furnace Category scrubber blowdown meeting 1977 Effluent Guidelines for Best Practical Control Technology Currently Available (BPCTCA). The advanced treatment methods, both singularly and in combination which were investigated on a pilot basis included: alkaline chlorination, clarification, filtration, (dual media and magnetic), ozonation, activated carbon and reverse osmosis.

The residual conventional parameters monitored included pH, temperature, suspended solids, BOD, oils and grease, phenol, cyanide, fluoride, ammonia, sulfide and dissolved solids. Priority pollutant samples were also collected from each process train investigated.

The studies were performed on-site using mobile pilot equipment designed to operate at a flow rate of 19 ℓ/min (5 gpm). Evaluation and comparison of the data were performed using the criteria: (1) process and/or treatment train performance, (2) capital and operating costs and (3) space requirements.

The results of the pilot program indicated that alkaline chlorination, ozonation and reverse osmosis were effective in reducing influent contaminants to below future BATEA levels. For all three promising technologies, proper pretreatment would be required. Costs associated with upgrading, of the blast furnace scrubber blowdown are currently being finalized. This project effort was funded by the Environmental Protection Agency - Industrial Environmental Research Laboratory under contract number 68-02-2671.

The information and conclusions presented in this paper are based on preliminary examination of data which will be subjected to extensive analysis and interpretation before it is considered final.

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* The BATEA limits used hereinafter throughout this paper refer to those proposed in 1974. New BATEA limits for the Iron & Steel Industry are expected to be proposed in 1980.

PHYSICAL-CHEMICAL TREATMENT OF STEEL PLANT WASTEWATERS USING MOBILE PILOT UNITS

INTRODUCTION

This project was initiated to provide an evaluation of the effectiveness of existing treatment technology for upgrading steel mill wastewater to Best Available Technology Economically Achievable (BATEA) limits for Blast Furnace Category scrubber wastewaters. The wastewater tested was effluent from an operating steel mill treatment system that met 1977 Effluent Guidelines for Best Practical Control Technology Currently Available (BPCTCA). This wastewater contained residual concentrations of suspended solids, BOD, phenols, cyanides, fluorides, ammonia compounds, sulfides, and dissolved solids. The in-depth pilot plant study was performed using mobile facilities containing physical-chemical treatment equipment.

Treatment processes evaluated during the study included: alkaline chlorination, chemical treatment, dual media filtration, magnetic filtration, reverse osmosis, ozonation and activated carbon.

The project objective was achieved through the performance of a program consisting of the three phases outlined below:

PHASE I - Bench Scale Investigation of a Blast Furnace Scrubber Blowdown Wastewater.

PHASE II - Design and Fabrication of the Mobile Treatment Facilities to House the Pilot Scale Equipment.

PHASE III - Operation and Evaluation of the Advanced Waste Treatment Pilot Plant Systems at a Blast Furnace Site.

The purpose of the first phase (bench-scale work) was to provide information concerning the treatment methods to be studied for the Phase II design and the Phase III pilot plant investigation (operation and evaluation). Of particular interest were such items as the pretreatment requirements, magnitude of operating variables, expected magnitude of treatment efficiency and effluent quality, selection of equipment and media, and pilot plant system design.

The second phase objective (System Design and Fabrication) was to provide a mobile pilot testing system for evaluating several advanced waste treatment technologies. The portable treatment system developed included the technology needed to remove the residual contaminants in the blast furnace BPCTCA wastewater to the extent that the wastewater was upgraded to meet BATEA requirements. Schematic representations of the mobile testing systems are shown in Figures 1 and 2. Trailer No. 1 housed the alkaline chlorination, chemical treatment, magnetic filtration and dual media filtration systems. The ozonator, activated carbon and reverse osmosis technologies were located in Trailer No. 2. The mobile system contained a high degree of automation which greatly assisted the operators during the study. All of

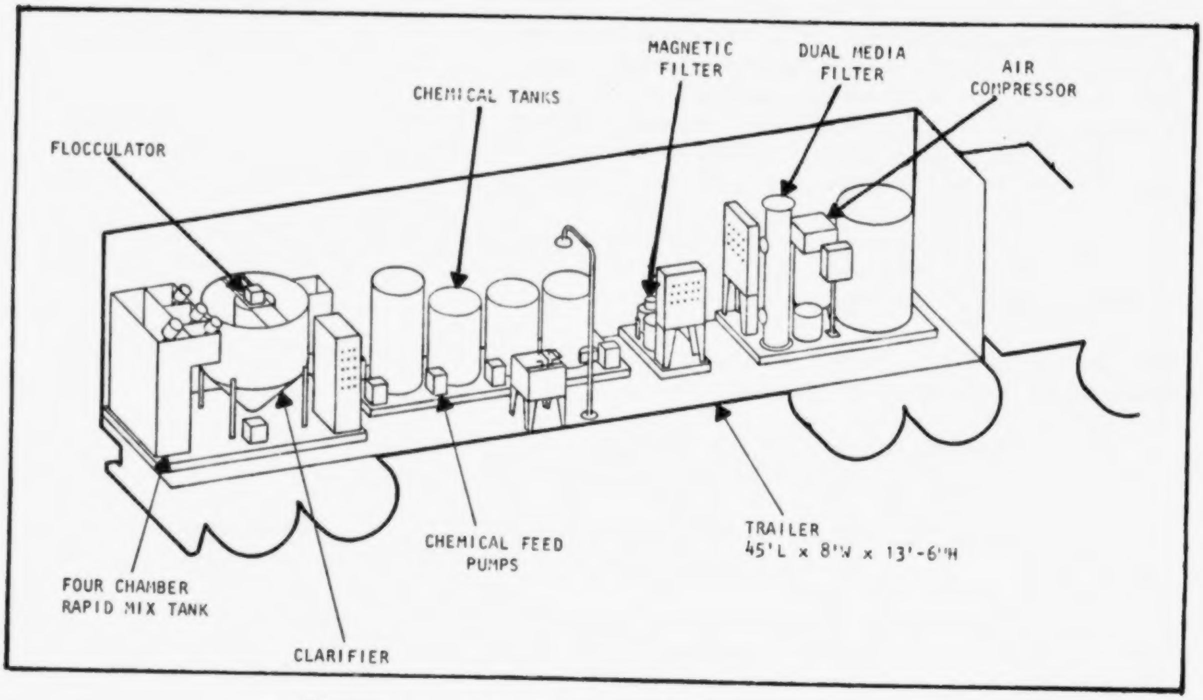

MAGNETIC FILTER
DUAL MEDIA FILTER
AIR COMPRESSOR
CHEMICAL TANKS
FLOCCULATOR
CHEMICAL FEED PUMPS
TRAILER
45'L x 8'W x 13'-6"H
FOUR CHAMBER RAPID MIX TANK
CLARIFIER

Figure 1. Steel plant mobile treatment system-trailer No. 1.

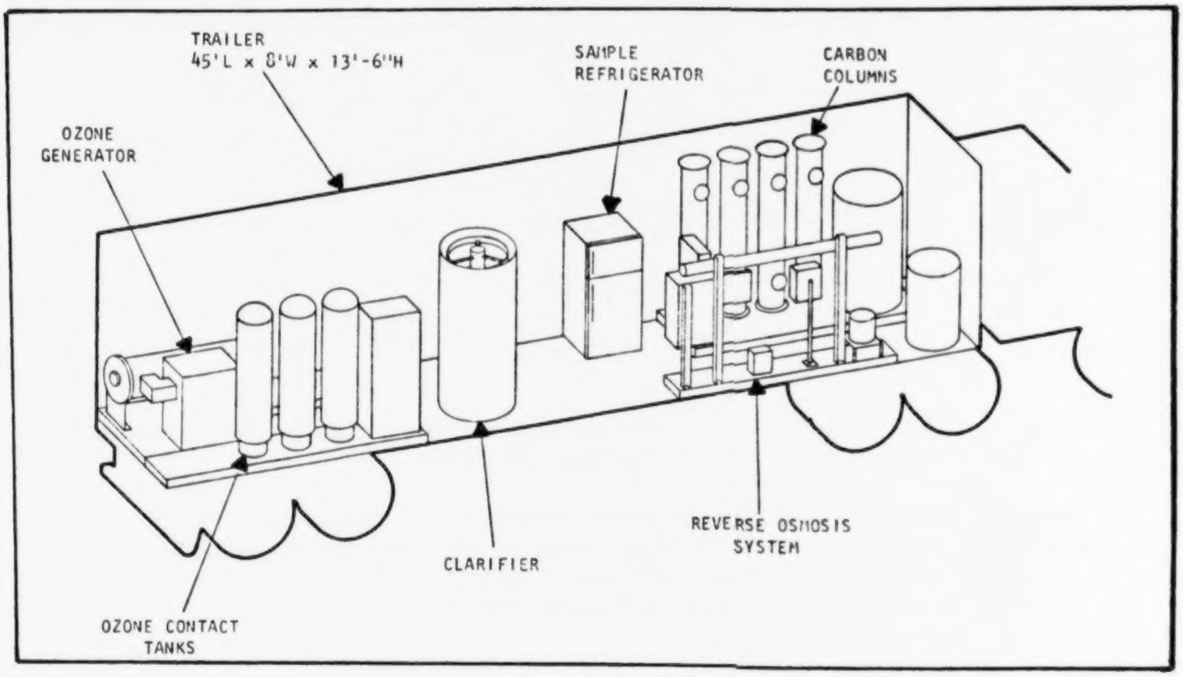

TRAILER
45'L x 8'W x 13'-6"H
SAMPLE REFRIGERATOR
CARBON COLUMNS
OZONE GENERATOR
REVERSE OSMOSIS SYSTEM
CLARIFIER
OZONE CONTACT TANKS

Figure 2. Steel plant mobile treatment system-trailer No. 2.

the treatment technologies were designed to treat a nominal flow of 18.9 ℓ/min (5 gpm).

During the pilot testing phase, the movable waste treatment systems were operated at the steel mill site to obtain an evaluation of the applicability of the selected treatment technology to the treatment of the respective wastewater. The study was conducted on a pilot plant scale of sufficient size to permit the development of performance and basic design criteria which were used to scale-up to full size equipment.

The advanced waste treatment methods, both singularly and in combination, which were investigated on a pilot basis in Phase III included those presented below:

1. FIL + O + CT
2. ACL + CT + AC
3. CT + FIL + RO + O (on ROB)
4. CT + FIL + RO + ACL (on ROB)

KEY

AC:	activated carbon
ACL:	alkaline chlorination
CT:	chemical treatment
FIL:	filtration-dual media or magnetic
O:	ozonation
RO:	reverse osmosis
ROB:	reverse osmosis brine

A schematic illustration of the process trains investigated for treatment of the blast furnace wastewater is shown in Figure 3.

For each treatment train investigated, samples and operational data were obtained for later use in assessing, evaluating, appraising and comparing the adequacy of the individual advanced waste treatment methods. Evaluation and comparison of the data were performed using the criteria:

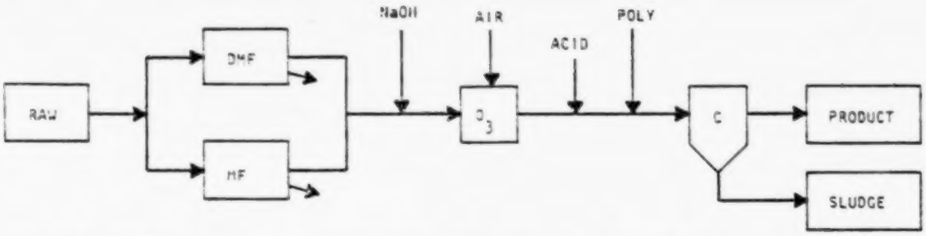
(1). process and/or treatment train performance
(2). capital and operating costs
(3). space requirements

EXPERIMENTAL RESULTS

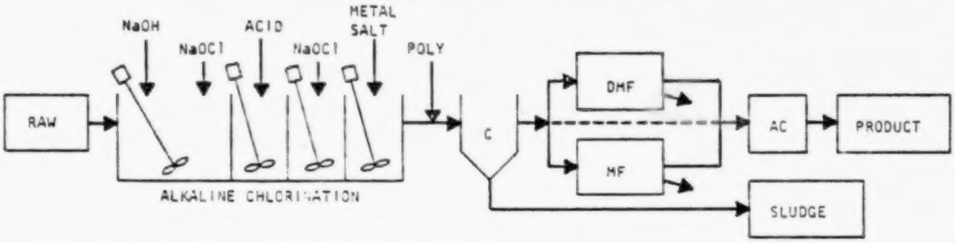
General

The blast furnace research site selected was located on the southern shore of Lake Michigan. The plant began production in 1964 and the hot metal facilities began production in 1969. The mill utilizes two furnaces. During the 15 week study, blast furnace production averaged 10,919 metric tons/day (12,029 tons/day), with a scrubber water blowdown flow of 5,397 m^3/day (1.426 mgd). Based on BATEA limits, the allowable pollutant concentrations in the effluent would be:

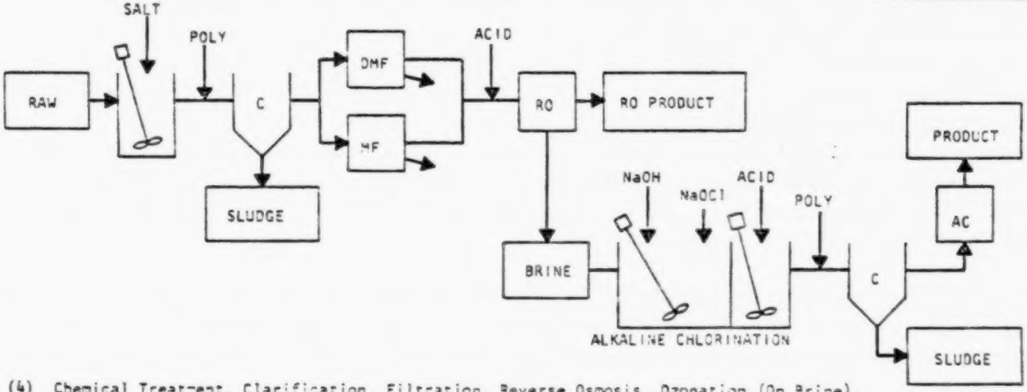
(1) Filtration, Ozonation Clarification


NaOH
AIR
ACID
POLY
RAW
DMF
MF
O_3
C
PRODUCT
SLUDGE

(2) pH Adjustment, Alkaline Chlorination, Chemical Treatment, Clarification, Filtration, Carbon Adsorption


NaOH
NaOCl
ACID
NaOCl
METAL SALT
POLY
RAW
ALKALINE CHLORINATION
C
DMF
MF
AC
PRODUCT
SLUDGE

(3) Chemical Treatment, Clarification, Filtration, Reverse Osmosis, Alkaline Chlorination (on brine), Carbon Adsorption


METAL SALT
POLY
ACID
RAW
C
DMF
MF
SLUDGE
RO
RO PRODUCT
BRINE
NaOH
NaOCl
ACID
POLY
ALKALINE CHLORINATION
C
AC
PRODUCT
SLUDGE

(4) Chemical Treatment, Clarification, Filtration, Reverse Osmosis, Ozonation (On Brine), Clarification

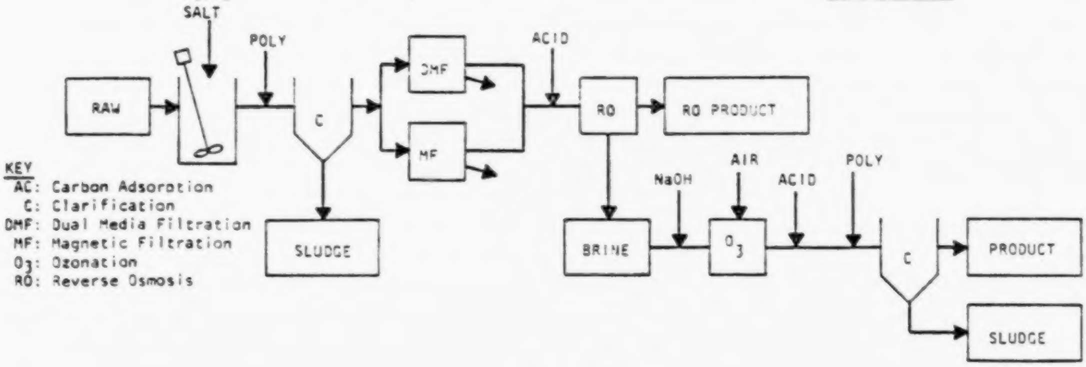

METAL SALT
POLY
ACID
RAW
C
DMF
MF
SLUDGE
RO
RO PRODUCT
BRINE
NaOH
AIR
O_3
ACID
POLY
C
PRODUCT
SLUDGE
KEY
AC: Carbon Adsorption
C: Clarification
DMF: Dual Media Filtration
MF: Magnetic Filtration
O_3: Ozonation
RO: Reverse Osmosis

Figure 3. Process trains investigated for treatment of the blast furnace waste water.

Parameter	BATEA Level Blowdown	 Reverse osmosis brine[1]
pH	6.0-9.0	6.0-9.0
Suspended solids, mg/ℓ	27	108
Ammonia, mg/ℓ	10.85	43.4
Cyanide-A, mg/ℓ	0.271	1.08
Phenol, mg/ℓ	0.543	2.17
Sulfide, mg/ℓ	0.334	1.34
Fluoride, mg/ℓ	21.71	86.8

1. Assuming reuse of the reverse osmosis product water so that only 25 % of the original blowdown volume is discharged.

Wastewater Treatment System

Each furnace has its own gas cleaning and cooling system and thickener. Each system consists of a dust catcher, a primary venturi scrubber, a primary washer, a secondary venturi scrubber, a gas cooler, and a thickener. A schematic of the system is presented in Figure 4. Both thickeners are 27.4 m (90 ft) in diameter, 5 m (16.5 ft) deep with a design overflow rate of 60.3 $\ell/min/m^2$ (1.48 gpm/ft^2). The thickeners were designed to yield an average effluent suspended solids of 50 mg/ℓ. The clarified overflow from the thickeners flows into the hot well of the Blast Furnace Closed Water Pumping Station. Make-up lake water may be added automatically as required for level control. The water is pumped from the hot well to the five, spray filled cooling towers.

The five units operate in series. The cooled water flows by gravity through a bar screen type trash rack to a cold well. Two stage, fixed speed, high lift pumps move the water to the booster pump stations located near each blast furnace. The water is then used for washing and cooling the blast furnace gas. Water is blown down from the discharge side of the high lift pumps as required. Blowdown is based on level control. A cyanide destruct unit is located on the blowdown line. The unit consists of an alkaline-chlorination system which is operated on an "as needed" basis to destruct excessive concentrations of cyanide and ammonia in the blowdown. The mobile pilot plant units' feedwater was taken from the blowdown line before the cyanide destruct unit.

Pilot Study Results

The results of the pilot program indicated that alkaline chlorination, ozonation and reverse osmosis were all capable of producing an effluent acceptable for discharge which meets BATEA limitations. A brief summary of the pilot findings for each of the above mentioned treatment technologies is presented below.

Alkaline Chlorination Treatment Train

The alkaline chlorination treatment train was successful in reducing influent concentrations of all parameters of concern to below BATEA levels. The

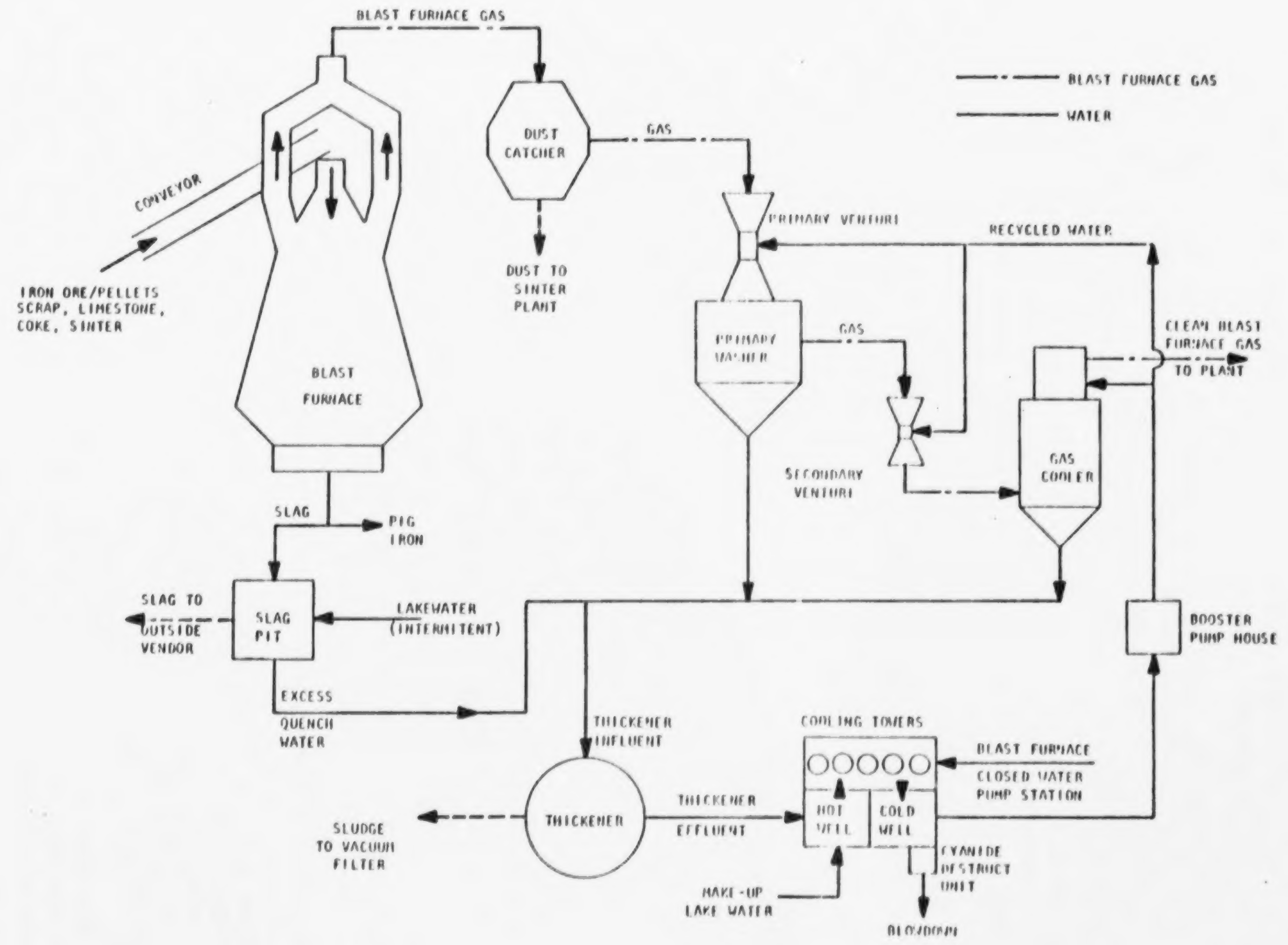

BLAST FURNACE GAS
BLAST FURNACE GAS
WATER
CONVEYOR
IRON ORE/PELLETS SCRAP, LIMESTONE, COKE, SINTER
BLAST FURNACE
DUST CATCHER
DUST TO SINTER PLANT
GAS
PRIMARY VENTURI
RECYCLED WATER
PRIMARY WASHER
GAS
SECONDARY VENTURI
GAS COOLER
CLEAN BLAST FURNACE GAS TO PLANT
SLAG
PIG IRON
SLAG TO OUTSIDE VENDOR
SLAG PIT
LAKEWATER (INTERMITENT)
EXCESS QUENCH WATER
BOOSTER PUMP HOUSE
THICKENER INFLUENT
COOLING TOWERS
BLAST FURNACE CLOSED WATER PUMP STATION
SLUDGE TO VACUUM FILTER
THICKENER
THICKENER EFFLUENT
HOT WELL
COLD WELL
CYANIDE DESTRUCT UNIT
MAKE-UP LAKE WATER
BLOWDOWN

Figure 4. Blast furnace gas cleaning water recirculation system.

treatment train consisted of elevating the pH of the incoming wastewater to 11.0-11.5 with addition of sodium hypochlorite for oxidation of cyanide. The waste was then neutralized for ammonia removal. The existing wastewater was dosed with chemical coagulants prior to clarification and the settled effluent was dechlorinated on activated carbon.

During the alkaline chlorination study, ammonia was found to be the limiting parameter for meeting BATEA requirements; that is, if ammonia was reduced below BATEA levels, all other oxidizable contaminants were also removed below required future limitations. Shown in Table 1 is a summary of the alkaline chlorination effluent data for selected runs. The results indicated that as the chlorine to ammonia ratio was increased, ammonia removal improved. Ammonia concentrations remained high until $Cl_2:NH_3$ ratios exceeded 7.3:1 and then dropped sharply as this ratio was increased. Chlorine to ammonia ratios from 6.9:1 to 15.2:1 were studied. Effluent ammonia values as low as 0.48 mg/ℓ were achieved. Breakpoint chlorination occurred at a chlorine to ammonia ratio of approximately 10:1. Excellent removals of cyanide-A were achieved at all $Cl_2:NH_3$ ratios investigated. Influent ammonia concentrations during the study were quite stable, ranging from 17.0 mg/ℓ to 46.0 mg/ℓ with an average of 33.4 mg/ℓ.

TABLE 1. BLAST FURNACE WASTEWATER
ALKALINE CHLORINATION DATA

Run no.	$Cl_2:NH_3$ ratio	Ammonia, mg/ℓ		Cyanide A, mg/ℓ	
		Inf.	Eff.	Inf.	Eff.
1	15.2:1	29.2	0.67	0.02	<0.01
2	10.0:1	32.9	0.48	0.19	<0.01
3	8.0:1	32.4	5.2	0.02	<0.01
4	7.4:1	46.0	6.95	0.18	<0.01
5	6.9:1	30.4	10.3	0.01	<0.01

Following alkaline chlorination, the wastewater was dosed with 100 mg/ℓ ferric chloride and 0.5 mg/ℓ polymer to improve effluent quality. The suspended solids removal averaged 93% with a range from 88-98%. The settled effluent was passed through a granular activated carbon system to reduce residual chlorine. The carbon columns were operated in an upflow-expanded bed mode to eliminate problems associated with the formation of nitrogen gas in the system.

In dechlorination of the scrubber blowdown, 88% of the influent available chlorine was removed with a contact time of 8.5 minutes. With a contact time of 20 minutes, a total chlorine removal of 98% was achieved. A linear flow rate of 0.163 m^3/m^2/day (4 gpm/ft^2) was used during the study.

Ozonation Treatment Train

Ozonation was a second treatment technology investigated to reduce the blast furnace scrubber blowdown to BATEA limits. The treatment train consisted of filtration, pH elevation to 10.5-11.5, ozonation, neutralization and clarification. Major treatment train components are discussed below.

During this study, both a dual media filter and a magnetic filter were investigated for suspended solids and turbidity removal prior to ozonation.

1. The filtration media used in the dual media filtration tests consisted of 39 cm (15 in.) of Red Flint filter sand and 43 cm (17 in.) of anthracite coal. Filtration removed significant quantities of suspended solids (83%) and turbidity (75%). From pilot test data analysis, influent feedwater contained an average suspended solids concentration of 84 mg/ℓ. Typical suspended solids feed to the ozone system following filtration was 14 mg/ℓ.

2. The magnetic filter reduced influent suspended solids by 70% and turbidity by 32%. Based on suspended solids and turbidity removal data, the dual media filter provided a higher quality feed water to the ozone process element.

Ozonation was found to be a reliable treatment technology for meeting BATEA guidelines. Operational variables investigated included hydraulic retention time and ozone dosage. Preliminary studies indicated that the ammonia limitation was the critical factor in meeting discharge levels. Therefore, the ozone test study was structured toward meeting the ammonia limitation.

For the scrubber blowdown discharge, the prefiltered wastewater was elevated to 10.5-11.5 prior to entering the ozone contact columns. The total applied ozone dosage was varied from 0-1,500 mg/ℓ. Contact times were adjusted between 60-240 minutes to determine optimum contactor retention times. Selected results of testing are shown in Table 2. The data indicate that ozone was effective in meeting BATEA limits. One test run was conducted at elevated pH using compressed air. Results varified that ozonation rather than stripping was the mechanism for removing the ammonia. For purposes of design, a 60 minute contact time was used with an applied ozone dose of 733 mg/ℓ.

Suspended solids present in the neutralized ozonated effluent were easily removed by clarification. For the ozonated scrubber blowdown, polymer was added at a rate of 0.5 mg/ℓ to improve settling. Suspended solids removal consistently averaged 95% or better at all flow rates investigated.

Reverse Osmosis Treatment Train

The reverse osmosis treatment train was the third successful group of process elements investigated for upgrading the BPCTCA blast furnace scrubber blowdown to BATEA discharge limitations. Technologies belonging to this treatment train included chemical treatment, filtration and reverse osmosis.

TABLE 2. BLAST FURNACE OZONATED WASTEWATER QUALITY

	Date			
	1/13	1/17	1/20	1/22
Run number	1	2	3	4
Contact time, min.	240	120	171	120
O_3 applied, mg/ℓ	1054	1205	1074	739
O_3 utilized, mg/ℓ	363	364	480	612
Parameter				
pH	7.90		6.90	7.60
SS, mg/ℓ	1	7	15	16
VSS, mg/ℓ	<1	3	5	5
Phenol, mg/ℓ	0.010		0.005	0.190
NH_3 as N, mg/ℓ	3.1	9.4	3.4	10
NO_3 as N, mg/ℓ		34.5		
TKN as N, mg/ℓ	1.1	4.8	0.67	12.7
S, mg/ℓ	<0.2	<0.2	<0.2	0.1
CN, mg/ℓ		<0.01	<0.01	0.03
CN_A, mg/ℓ	<0.01	<0.01	<0.01	0.03
F, mg/ℓ	10.8	11	12	16.2
TOC, mg/ℓ	<2	6	5	<1
BOD, mg/ℓ		<5		
Color, APHA units	5/10	0/5	5	10
O&G, mg/ℓ	<1			

Chemical treatment and clarification was required to remove suspended solids and turbidity from the scrubber blowdown prior to filtration and application by the reverse osmosis system. Chemical addition consisted of alum (50-150 mg/ℓ) and polymer (0.5 mg/ℓ). Turbidity removal averaged 68% while a 83% reduction in suspended solids was also achieved.

Dual media and magnetic filtration were the technologies investigated to provide final pretreatment to the wastewater before desalting by the reverse osmosis membranes. Superior suspended solids and turbidity removal was achieved by the dual media filter and this technology was used to provide feed to the reverse osmosis system.

The reverse osmosis testing program was performed in two phases. Phase 1 was operated at a 33% product water recovery while a 75% recovery was utilized in Phase 2. The two phases were used to obtain expected product water quality data and also cleaning information. TFC Model 4600 polyamide spiral wound membranes were used during the study.

The system was operated continuously over the test period and a total of 409.5 hours were put on the RO membranes.

Projected product water quality, assuming a 75% recovery is shown in Table 3. The RO rejected significant concentrations of all BATEA parameters to the extent that the product water could be discharged directly or reused in the mill. Brine treatment by either alkaline chlorination or ozonation would be required prior to discharge. Information on treatment of this sidestream was also obtained during the study.

TABLE 3. BLAST FURNACE PROJECTED REVERSE OSMOSIS PRODUCT QUALITY

Parameter	Product quality range
pH	5.35-5.75
SS, mg/ℓ	3-4
VSS, mg/ℓ	1-3
Phenol, mg/ℓ	<0.054
NH_3 as N, mg/ℓ	9-10
NO_3 as N, mg/ℓ	<0.02
TKN as N, mg/ℓ	10-12
S, mg/ℓ	<0.2
CN, mg/ℓ	<0.01
CN_A, mg/ℓ	<0.01
F, mg/ℓ	0.40-0.45
TOC, mg/ℓ	<2
BOD_5, mg/ℓ	<2
COD, mg/ℓ	<5
TP as P, mg/ℓ	<0.01
TDS, mg/ℓ	60-70

Alkaline chlorination of the reverse osmosis brine consistently reduced the ammonia concentration to less than BATEA levels provided the chlorine to ammonia ratio was in excess of 7.6:1. Ammonia concentrations continued to drop as the Cl_2:NH_3 ratio was increased above 7.6:1 until breakpoint was reached at a ratio of about 10:1. Total cyanide and cyanide-A values were typically less than 0.01 mg/ℓ for the effluent wastewater.

During ozonation of the reverse osmosis brine, the influent pH was elevated to 11.5-12.0 prior to applying ozone dosages ranging from 0-3,065 mg/ℓ. Hydraulic detention times of 120-400 minutes were studied. To meet discharge requirements, a dosage of approximately 9 mg of ozone were required for each milligram of ammonia in the effluent.

The pilot scale data were evaluated and submitted to vendors for scale-up to full size equipment. Costs were then summarized for the treatment trains that met BATEA requirements. These cost summaries are shown in Table 4.

The data indicate that for a 5,678 m^3/day (1.5 MGD) design, the alkaline chlorination treatment train would have a capital cost of $1,032,700. The corresponding operating costs including amortization of capital would be $2.856/3,785ℓ ($2.856/1,000 gal.). This compares to an operating cost of $5.404/3,785ℓ ($5.404/1,000 gal.) for ozonation and $4.547/3,785ℓ ($4.547/1,000 gal.) for reverse osmosis assuming ozonation of the brine. For reverse osmosis treatment with alkaline chlorination of the brine, the expected operating cost is $6.779/3,785ℓ ($6.779/1,000 gal.). The above costs are for treatment only and do not include the cost of handling and disposing of the sludge residues generated.

Space requirements are also given in Table for a 5,678 m^3/day (1.5 MGD) system. The ozonation treatment train has the lowest area requirement [754 m^2 (7,980 ft^2)] of all of the systems evaluated.

SUMMARY AND CONCLUSIONS

1. The results of the pilot program have indicated that alkaline chlorination, ozonation and reverse osmosis (RO) were effective in reducing influent contaminants to below Best Available Technology Economically Achievable (BATEA) levels in the treatment of blast furnace scrubber blowdown.

    a. Pretreatment requirements include:
        1. For alkaline chlorination: none
        2. For reverse osmosis: chemical clarification and filtration
        3. For ozonation: filtration

    b. Post-treatment requirements:
        1. For alkaline chlorination: chemical clarification and activated carbon
        2. For reverse osmosis: brine treatment by alkaline chlorination or ozonation
            (a) Following alkaline chlorination of the RO brine, the wastewater would require clarification with polymer and dechlorination by activated carbon.
            (b) After RO brine treatment by ozonation clarification with polymer is required.

2. Alkaline chlorination was the least cost alternative treatment train investigated. Expected capital investment for a 5,678 m^3/day (1.5 MGD) is $1,032,700. The corresponding operating costs including amortization of capital is estimated at $2.86/3,785ℓ ($2.86/1,000 gal.).

3. Ozonation has the lowest system area requirement of 754 m^2 (7,980 ft^2). This compared to 1,098 m^2 (11,500 ft^2) for the alkaline chlorination treatment train.

TABLE 4. TREATMENT TRAIN COST AND
SPACE REQUIREMENTS
5,678 m^3/day (1.5 MGD) DESIGN

Process	Capital Costs $	Operating Costs $/3,785ℓ ($/1,000 gal.)	Space Requirements m^2 (ft^2)
TRAIN NO. 1			
Alkaline Chlorination	120,900	1.19	426 (4,400)
Chemical Treatment	103,800	0.19	300 (3,100)
Activated Carbon	808,000	1.476	372 (4,000)
Total	1,032,700	2.856	1,098 (11,500)
TRAIN NO. 2			
Filtration	35,100	0.064	251 (2,700)
Ozonation	11,250,000	5.20	203 (2,180)
Clarification	133,700	0.14	300 (3,100)
Total	11,418,800	5.404	754 (7,980)
TRAIN NO. 3			
Clarification	93,000	0.17	300 (3,100)
Filtration	36,400	0.067	251 (2,700)
Reverse Osmosis	473,500	1.16	333 (3,590)
Ozonation-Brine	3,225,000	2.90	93 (1,000)
Clarification-Brine	78,500	0.25	70 (780)
Total	3,906,400	4.547	1,047 (11,170)
TRAIN NO. 4			
Clarification	93,000	0.17	300 (3,100)
Filtration	36,400	0.067	251 (2,700)
Reverse Osmosis	473,500	1.16	333 (3,590)
Alk. Chlor.-Brine	93,600	2.75	325 (3,500)
Clarification-Brine	78,500	0.25	70 (780)
Act. Carbon-Brine	326,000	2.382	265 (2,850)
Total	1,101,000	6.779	1,544 (16,520)

ACKNOWLEDGEMENTS

Rexnord acknowledges the cooperation and support of the U.S. Environmental Protection Agency. The assistance given by Robert Hendriks, Project Officer was received with much appreciation.

The information contained in this paper is part of a draft final report being prepared for the U.S. Environmental Protection Agency. Modifications to the enclosed material prior to publication of the final report are probable.

STUDY OF NON-U.S. WASTEWATER TREATMENT TECHNOLOGY AT BLAST FURNACES AND COKE PLANTS

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ABSTRACT

An engineering study is currently being performed to determine the applicability of wastewater treatment technology being used at blast furnaces and coke plants outside of the United States to the iron and steel industry in the United States. This study is being performed under Contract No. 68-02-3123 issued by the U.S.E.P.A., Metallurgical Processes Branch, Industrial Processes Division, IERL, RTP North Carolina.

Steel plants in Western Europe, Australia, Taiwan, Japan, North and South America and Africa were visited and discussions held with appropriate plant and corporation personnel. Cooperation by the plants has been very good. Where permitted, the actual treatment facilities were visited. Where available, influent and effluent quantities and qualities were provided as well as treatment systems operating parameters.

Regulatory agencies, an iron and steel industry association and a centralized treatment facility were also visited to determine effluent regulations, pretreatment constraints and the rationale for the required effluent quality.

Preliminary findings will be presented in this paper. However, as of this presentation there is still ongoing correspondence between Hydrotechnic and the steel companies visited to continue to develop bases for adapting non-US technology to the United States blast furnace and coke plant waste treatment facilities.

STUDY OF NON-U.S. WASTEWATER TREATMENT TECHNOLOGY AT BLAST FURNACES AND COKE PLANTS

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INTRODUCTION

On September 29, 1978 Hydrotechnic Corporation received an assignment from the U.S.E.P.A. to study non-US blast furnace and coke plant waste treatment facilities with the view towards applying any superior technologies found at similar production facilities in the United States. This project is to determine if such technologies do in fact exist, the efficiencies of these technologies and their applicability to US steel plants. As of the presentation of this paper the technologies are still being evaluated and any conclusions drawn herein are tentative.

METHODOLOGY

The obvious first step in meeting the goals of the assignment was to obtain permission to visit as many of the steel plants outside of the United States which, based on prior knowledge, were apt to have facilities installed that might be considered as being superior to those presently in operation in the United States. Using the in-house information at Hydrotechnic, a literature search and contacts with steel people throughout the world, the plants were selected. In addition, the assistance of the International Iron and Steel Institute in Brussels was requested but they suggested the steel companies be contacted directly. Additional candidate plants were obtained from steel plant equipment manufacturers and from other steel plants. As a result, twelve steel plants in seven West European countries, seven in Australia and the Far East, two in Mexico, three in South Africa and two in South America were visited to observe and discuss their treatment systems. Prior to the visits, questionnaires were prepared and mailed to each of the plants with a request that they be completed and given to us when we arrived at the plant. These questionnaires were fairly detailed and it was not expected that all data requested would be available at every plant. Most questionnaires were completed to some degree and they were ready when we arrived to hold more detailed discussions. After the discussions, most plants permitted visits to the treatment facilities.

Upon our return to the United States, trip reports including our understanding of the information provided were prepared and sent to the respective plants visited for verification of the process and data contained therein.

Meetings were also held with government regulatory agencies in Sweden, Holland, the United Kingdom, Australia, Taiwan, Japan, Mexico, Brazil and South Africa to determine what regulations have been established for steel plant effluents. The West German government referred us to the Verein Deutcher Eisenhuttenleute, an organization similar to the AISI in North America. A centralized wastewater treatment plant was observed where an entire river polluted with municipal and industrial wastes (including those from steel plants) is diverted, passed through the treatment plant and discharged.

Since the primary objective of this project is to determine foreign technologies that offer advantages over domestic practices, this study also includes the researching of existing methods utilized by steel plants in this country for treatment of coke plant and blast furnace wastes and near term research for treatment of these wastes.

As originally conceived, a second phase of this project was to consist of the sampling of foreign waste treatment facilities influents, effluents and selected intermediate streams for parameters regulated under the existing effluent limitations guidelines and also for priority pollutants. Not all plants visited were receptive to this sampling program but many expressed a willingness to cooperate.

However, based on the analytic data provided, only portions of the observed wastewater treatment practices appeared to be applicable for transfer to domestic practice. This sampling phase was deleted from the project in favor of more detailed engineering study to determine the adaptability of processes observed to the United States practice.

Major differences exist between the establishment and enforcement processes of regulations in the United States and other nations. Foreign regulations are most often established on a case by case basis with respect to receiving water quality, feasibility and economics of treating the discharges to a given quality, benefits to be gained and quantities of water used. In addition, in many cases local agencies rather than the national governments exert the major authority. In Great Britain, it is the local water basin authority; in Japan, it is the prefecture; in Australia and the Republic of China, it is the state although the national government establishes the national goals.

Most government agencies do not set standards which are then passed on to the industry for comment. The industry takes an active part of the standard setting procedure. In two of the countries visited, additional government agencies are also included in the standard setting procedure. In the Netherlands, the Ministry of Economic Affairs is consulted and in Japan the Ministry of International Trade and Industry takes an active part in the procedure. In some countries, the government owns or has a major investment in the industry.

In countries that are members of the European Economic Community, a directive of the Council of the European Communities with respect to "pollution caused by certain dangerous substances discharged into the aquatic environment of the Community" is used as the general guideline for all discharges. This includes surface and ground water within the member countries and also ocean discharges.

Although intervener groups are permitted to contest regulations, the technical merits of their arguments are determined by hearing procedures rather than courtroom adversary proceedings. There is a minimum of media comments.

Some countries, notably the Netherlands and West Germany, establish a fee for discharges based on quantity and quality. For example, one plant in Europe has to pay a tax calculated on the basis of:

$$\text{Annual Tax} = \$10 \left(\frac{m^3/\text{day}}{180} (\text{COD} + 4.57\ \text{N})\right) \quad \text{COD \& N in mg/l}$$

If the plant does not meet minimum concentration standards for specified parameters there are additional fines levied.

The objective of this paper, however, is to discuss the technology observed. Some aspects of regulations have been discussed only to provide an understanding of the possible incentives there are for the steel plants to treat their wastes. Other incentives exist, however, in addition to regulatory constraints. Water withdrawn from public water supplies, be it a stream or aquifer, in many cases, must be paid for. One plant visited obtains the highest quality water that it requires from wells located on its own property and must pay the equivalent of 14¢ per cubic meter withdrawn (53¢ per 1000 gallons) to local water authorities. It is therefore to the plants' economic advantage to treat water and maximize reuse. The plant mentioned above reports that 97 per cent of all water used in the plant is water that has been used, and recirculated either with or without treatment.

BLAST FURNACE WASTE TREATMENT

Blast furnace gas cleaning wastes are generally treated by sedimentation - in some instances with polyelectrolyte addition, cooling and recirculation. One plant visited discharged their flue dust laden water without settling although they are operating under a directive to install settling facilities by 1982. Other plants - generally those using salt water - do not recirculate after settling.

Only one of the plants visited practiced any treatment of the settled gas cleaning wastewaters for removal of any of the U.S.E.P.A. guideline parameters. Many of the plants do not blow down their recirculation systems per se. They blow down via sludge discharge or they use the blow downs to quench slag. The one plant that does treat for removal of cyanide and phenol uses Caro's Acid (permonosulfuric acid - H_2SO_5) to reduce the levels to the required 0.2 mg/l CN and 0.5 mg/l phenol. The normal influent level of phenol at that plant is 2 mg/l.

One plant reported that the addition of polyphosphate in the cooling tower aids in CN removal but at CN levels over 10 mg/l it does not work. Another plant reported that they had tried to remove CN using polyphosphate but successful removals could not be obtained. That same plant reported that a form of CN has been produced in their blast furnaces that is resistant to alkaline chlorination.

At two of the plants visited CN reductions were noted between gas cleaning discharges and the plant effluent without any intentional CN treatment installations. One of these plants operates its lone blast furnace on a five day per week basis and shuts down on week-ends. Since this plant is in a cold climate, steam was injected into the gas cleaning water collection pond to prevent freezing and CN was observed to be reduced from 30 mg/l to 2.4 mg/l. Stripping appears to be the reduction phenomenon.

The other plant that showed incidental reduction of CN was one that utilized the sludge withdrawal from the clarifiers as the total gas cleaning system blowdown. The sludge is deposited in sludge lagoons which is maintained at an alkaline pH, by either adding caustic or by combining cold rolling mills waste with the sludge. The water seeps through the ten meter depth of sludge and is collected at the underside by open-jointed pipes and discharged to a river. The CN is reduced from a level of 0.2 mg/l to 0.1 mg/l. The plant has theorized that the removal mechanism is the formation of metallo cyanide complexes which are adsorbed in the sludge. Zinc reductions have also been noticed and have been accounted for as the precipitation of zinc as a hydroxide which remains in the sludge due to filtering action.

At two plants, one in West Germany and one in Japan, aeration prior to discharge to the clarifiers was an integral part of the gas cleaning water recirculation system. The purpose is to strip CO and CO_2 from the water and to precipitate $CaCO_3$. A portion of the clarifier sludge is recycled to act as a seed and enhance precipitation and sedimentation.

At each of the plants visited inquiries were made as to the sources and compositions of their ores and coals. The objective was to attempt to correlate wastewater characteristics with the type of coal and/or ore used. Unfortunately virtually every plant has a multitude of sources and the ores and coals are blended to meet the plants' production objectives. Therefore, the correlation hoped for was impossible.

Data for several of the gas cleaning waste recirculation water systems observed are shown in Table 1.

COKE PLANT WASTE TREATMENT

Many modes of operation and distribution of responsibility were reported at the coke plants visited. One plant has a phenol recovery system owned by an outside agency but operated by the plant; some plants have the coke plant owned and operated by chemical companies although located on the steel plant site and one coke plant was not an integral part of any steel plant proper. Most coke plants, however, are owned and operated by the respective steel plants. Of the sixteen coke plants visited, four did not treat the final coke plant effluent other than passing the excess ammonia liquor through free ammonia stills; one of these plants also operated a dephenolizer. Two of these plants utilized the excess ammonia liquor diluted with other plant wastes for coke quenching and the other two discharged the wastes with other plant wastes to a river. This river receives wastes from other industries and, at the mouth, the entire river is diverted from an improved natural course, treated biologically and discharged to its natural course.

All of the biological treatment plants observed were single stage, activated sludge. One plant operated three banks of three basins each in series for a total of nine basins. Each series of three basins has its own final settling facility. In effect, three separate cultures are maintained.

Table 2 presents data from five plants that operate biological treatment systems. It can be seen that there are wide variations in concentrations of the various parameters entering the plants, and leaving the plants, although the detention times are relatively uniform. There are also operational variations i.e., some do and some do not utilize dilution water. Generally it can be seen that the single stage biological systems following free ammonia stills and with nutrient addition in the form of phosphoric acid produces good reductions of phenols and cyanide, poor reductions, if any, of ammonia and erratic COD reductions.

One plant visited had the complete treatment train as suggested in the development document guidelines, i.e. biological treatment, settling, filtration and activated carbon adsorption. The data for this plant is not presented here because the limited amount of data provided us has not been verified by the plant.

Two of the plants visited remove tar from their coke plant waste stream in coke filters prior to discharge to the aeration basins. The tar laden coke is then blended with coal and recharged to the coke ovens. One plant combines sanitary wastes with coke plant wastes for biological treatment.

Some of the plants visited controlled charging and pushing emissions by scrubbing systems. The water from all of the systems observed was discharged as makeup to the quench systems.

GENERAL

Good housekeeping was evident at all of the plants visited. Very few leaks and drips of equipment were observed, no treatment facilities appeared to be hydraulically overloaded and no water was observed to be running for no apparent purpose. Valves are opened only when needed and closed when the need has been satisfied.

Green areas are prevalent in all of the post-war plants and in fact, at one plant many rabbits were observed within the plant grounds.

There is a great deal of concern with respect to noise. Most equipment is sound-proofed and green buffer zones are created between the plants and the surrounding populated areas.

CONCLUSIONS

Based on the data obtained during the plant visits, it was concluded that sampling of the waste treatment facilities of the plants would not serve any useful purpose. None of the plants visited as of this writing have shown a complete system that would be considered as exemplary and the limited data available bears this out. However, portions of systems appear to show promise for further research and do merit further investigation. Extremely preliminary conclusions are that coke filters at biological plants may be useful to enhance the biological treatment even though electrostatic precipitators are used for tar removal. Aeration of blast furnace gas washer water may allow increases in the cycles of concentrations, thereby reducing the blowdown that would require treatment. Utilizing flue dust as a filter medium at an optimum pH level may be able to reduce cyanide and metals concentrations. This could be used as a unit operation in the treatment of blast furnace gas washer blowdown.

As stated earlier, only limited data was available for the guidelines parameters and no data was available for priority pollutants. All of the data received as of this writing is from steel plants in Western Europe and Australia and the Far East. These data are still being analyzed; therefore, further conclusions may still be drawn. Visits to the additional plants in Mexico, South America and South Africa may provide additional treatment concepts that may be applicable to the U.S. iron and steel industry.

TABLE I

BLAST FURNACE GAS CLEANING WATER

Plant	Total Plant BF Capacity		BF Cleaning Water Applied m³/hr	BF Cleaning Water Blowdown m³/hr	Percent Recycled	Disposition of BD
	No.	Cap. Mg/day				
E-1	5	50,000	7600	480	93.7	To Bay
FE-1	1	8,000	1125-1500	83-125	92.1	To slag quench
E-2	7	62,000	4445	68 50	97.3	Sludge and to river
E-3	2	4,500	600-900	40-60	93.3	To river
FE-2	(Typ)	800	1000	150 20	83	To Bay and sludge
E-4	2	1,400	470	1.7-4.2	>99	To river
E-5	1	1,200	155	3	98	To river via pig-caster
E-6	2	9,000	2400	21	99	Sludge, filtrate to river

TABLE 2

COKE PLANT WASTE TREATMENT

Plant	Coke Ovens	Capacity (Mg/day)	WAL (m^3/hr)	Dilution Added (m^3/hr)	Det. Time (hrs)	Phenol		CN		NH$_4$		COD	
						In	Out	In	Out	In	Out	In	Out
E-7	100	4730	25	up to 75		100(1)	1.02(1)	3.72(1)	0.62(1)	527(1)	340(1)	662(1)	180(1)
E-1	430			850(2)(3)	24	510	2.0	98	1.02	1010	1010	1380	68
E-2	440	3920		227(3)	22	900	18	13	0.9	115	470	3300	411
E-8	500	6500	70	0	21	400- 700	5-35	1-10	1	1000- 1800	1000- 1800	2000- 3000	900- 1000
E-9	54	2000	40	0	24	500- 600	0.3	0.2- 0.3	0.14	900- 1000	1350	NR	NR

(1) Better of 2 values reported.
(2) Design capacity.
(3) Individual flows not reported.

All analyses reported as mg/l.

Symposium on Iron and Steel
Pollution Abatement Technology

October 30 to November 1
Chicago, Illinois

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"Formation and Structure of Water-Formed Scales"

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ABSTRACT

After a brief review of the general problems associated with water-formed scales in steelplant recycle/reuse systems, the results of a detailed investigation on the initiation of calcium carbonate scales are presented. In particular, the structure of thermally-induced calcite deposits under a variety of experimental conditions are described with the help of scanning electron micrographs. The range of supersaturation for scale deposition on metallic substrates is defined and the transition from equiaxed to acicular crystal formation is characterized. The significance of the results in connection with the avoidance of deleterious scales are summarized briefly and a few suggestions for on-line sensor and control devices for steelplant water systems are made.

"FORMATION AND STRUCTURE OF WATER-FORMED SCALES"

INTRODUCTION

The technological developments in the treatment, reuse, and recycling of water in integrated steelplants depend in part upon the development of adequate control procedures for the avoidance of scale formation in a variety of steel operations. Several papers in this Symposium have described particular problems associated with deleterious scales. For the minimization of blowdowns and optimization of recycle/reuse systems, it is necessary to understand the tolerable levels of dissolved salts and, in some cases, suspended solids in different streams. In the present communication, some particular information on the formation of calcium carbonate scales under laboratory conditions is presented. The work is part of a more comprehensive investigation on the control of scale formation in steelplant water systems.

EXPERIMENTAL

Several types of water recirculation systems have been used in the laboratory to study the initiation and rate of formation of calcite scales on metal substrates. Figure 1 shows one of the assemblies used for studying thermally-induced scales. The appearance of a stainless steel substrate exposed to unstable circulated water is shown in Figure 2.

Instability has been established by a variety of methods including the addition of Na_2CO_3, pH adjustment, agitation with CO_2 gas of varying partial pressure, and temperature. The heating coil shown in Figure 1 enables the establishment of a substrate temperature in excess of $100^{\circ}C$. Five thermocouples are attached to the back of the substrate sample in order to record the temperature profile.

RESULTS

Figure 3 shows some of the results obtained with the described test unit. At excessive levels of supersaturation, general precipitation of $CaCO_3$ occurred throughout the water system. However, a region of intermediate non-equilibrium conditions was established wherein scale formation occurred in the absence of general precipitation. The reproducibility of these results is shown in Figure 4.

Normalized scale densities after a 10 hour exposure to water at a degree of supersaturation equal to twenty are shown in Figure 5.

In the present communication, the initiation of scales is of principal interest. Scanning Electron Microscopy (JEOL JXA-35 with EDAX) was used to characterize the initial crystallization. Representative micrographs are shown in Figures 6 and 7. Debeye-Scherrer patterns showed no evidence of aragonite and clear evidence for calcite as the dominant structure.

For short incubation periods and relatively low sample temperatures, equiaxed crystallization was favored. At higher temperatures, acicular crystals dominated.

DISCUSSION AND CONCLUDING REMARKS

Substrate condition influences the initiation, or nucleation, of calcite on metallic surfaces. Minute polishing scratches can markedly enhance crystallization even at very low levels of supersaturation. The experimental test cell described is a useful technique for evaluating the instability of circulated waters and for evaluating the effectiveness of surface coatings and inhibitors.

The results presented in this brief communication represent a small part of the entire experimental program. The test cell shows promise for use as an on-line sensor for scale formation control. Proposed modifications include the incorporation of several additional thermocouples which would enable the detection of scale formation without visual observation. The thermocouple outputs can yield information on both the initiation and rate of scale development. However, the suitability of such a sensor in a complex water stream containing dissolved salts in various combinations and a variety of suspended solids must be demonstrated.

ACKNOWLEDGEMENTS

Yu-Sue Won, Adil Khan, and John Newman have made significant contributions to the experimental program. The support of the U.S.E.P.A. and technical direction of Mr. Norman Plaks and Mr. John Ruppersberger are appreciated greatly. While no references are cited specifically, the contributions of many earlier and contemporary researchers in the field have been of immense value.

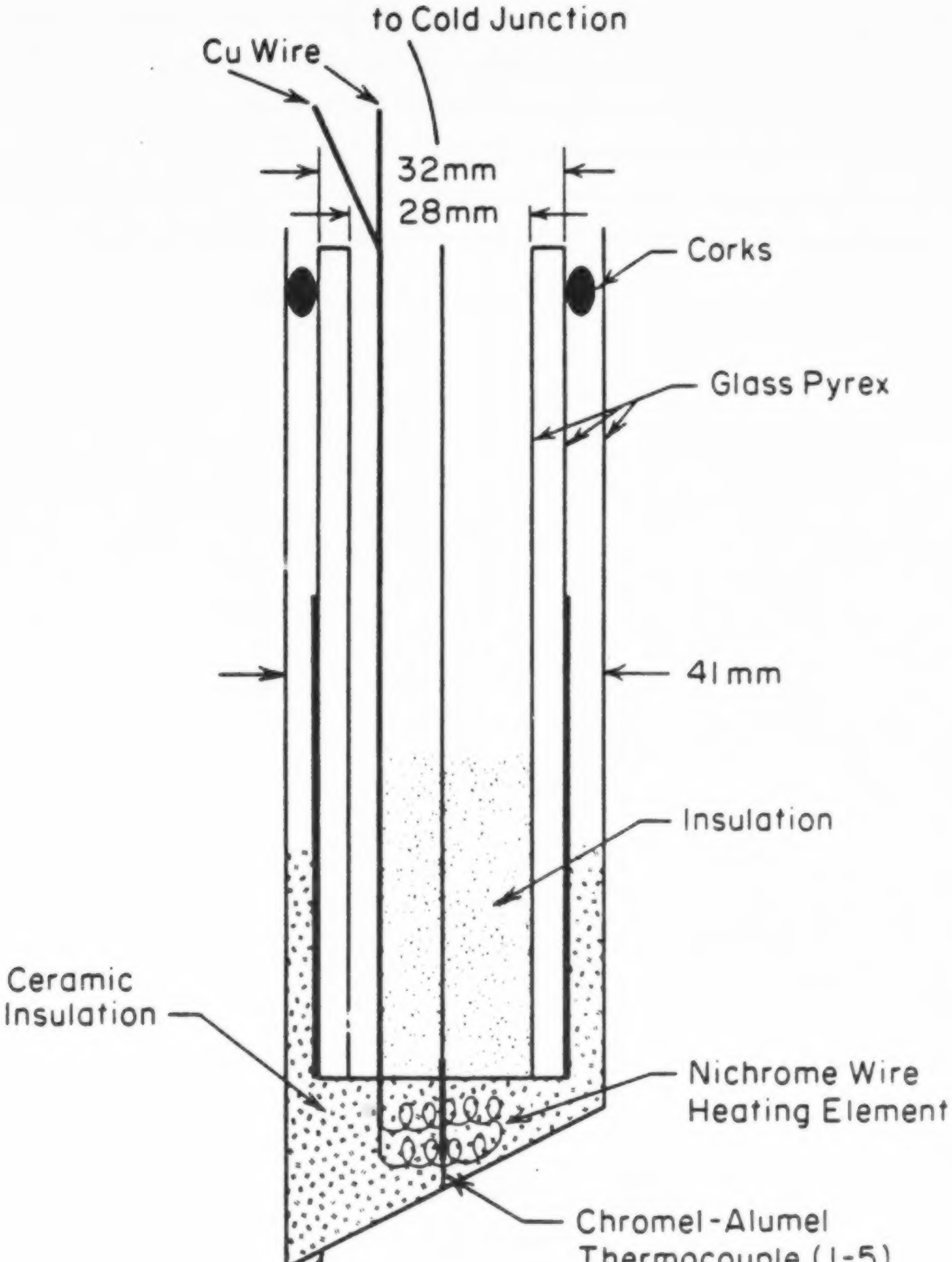
to Cold Junction
Cu Wire
32mm
28mm
Corks
Glass Pyrex
41mm
Insulation
Ceramic Insulation
Nichrome Wire Heating Element
Chromel-Alumel Thermocouple (1-5)
Metal Sample Sealed on Glass

Figure 1. Schematic Diagram for Studying Thermally-Induced Scales.

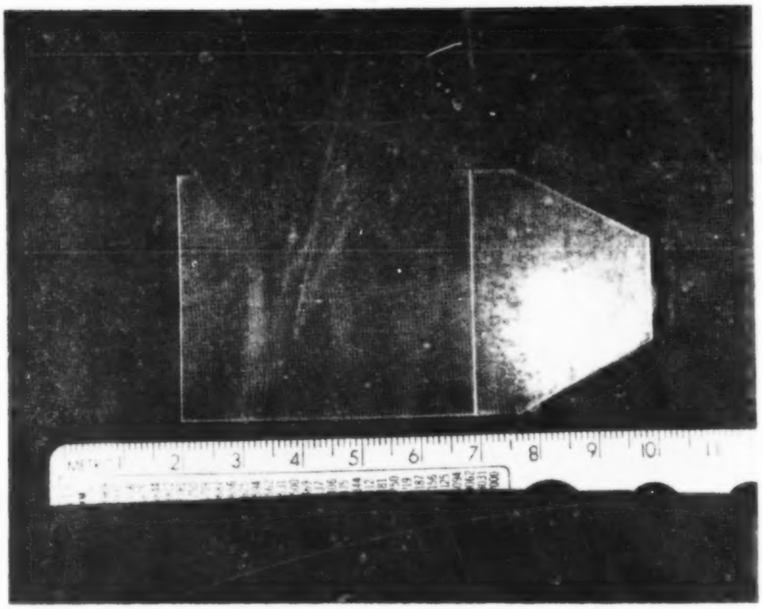

Figure 2. A Stainless Steel Substrate After Exposure to Unstable Water. (Note scale deposit in region on the right side.)

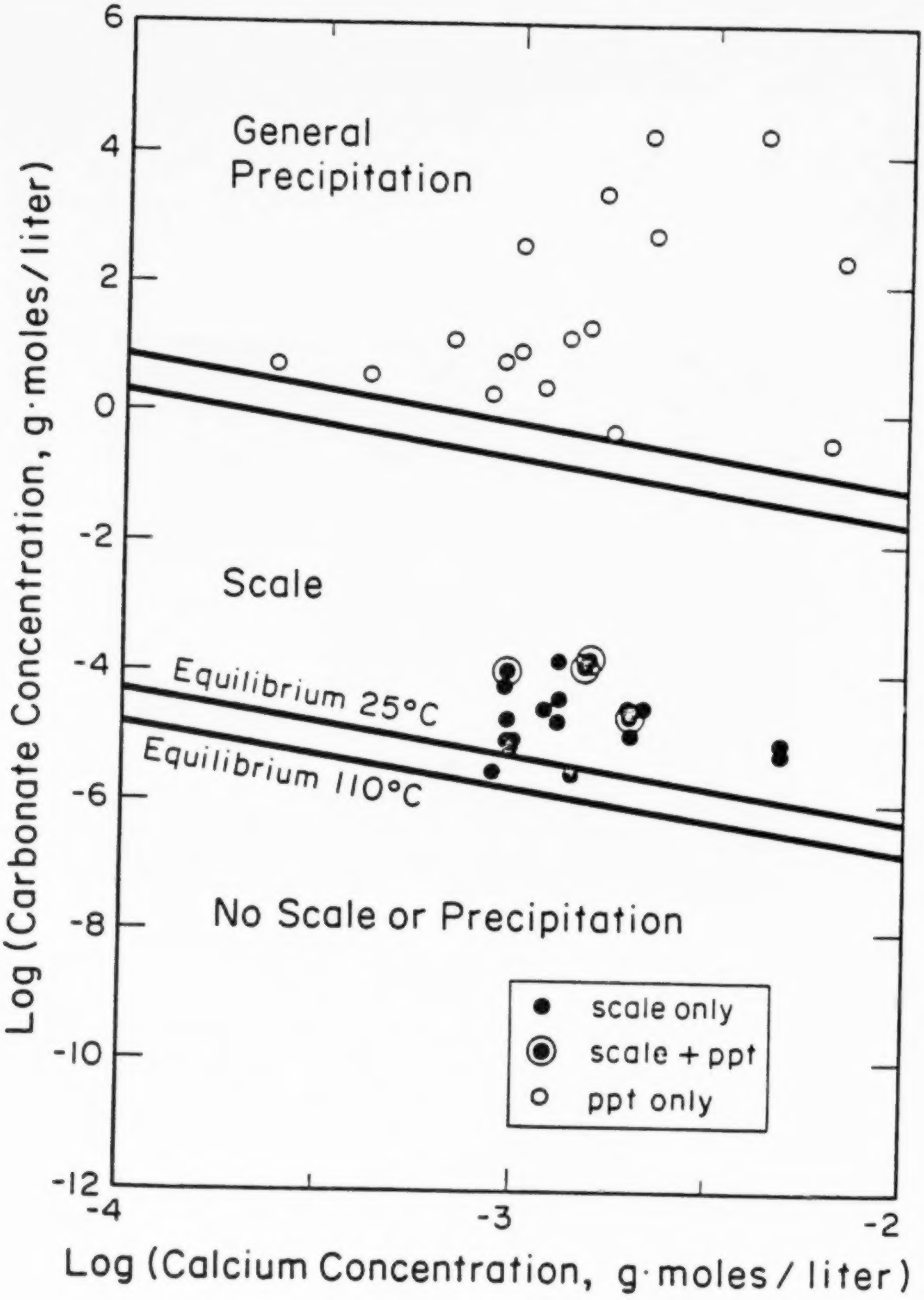

Figure 3. Regions for Stability, Scale Formation, and General Precipitation.

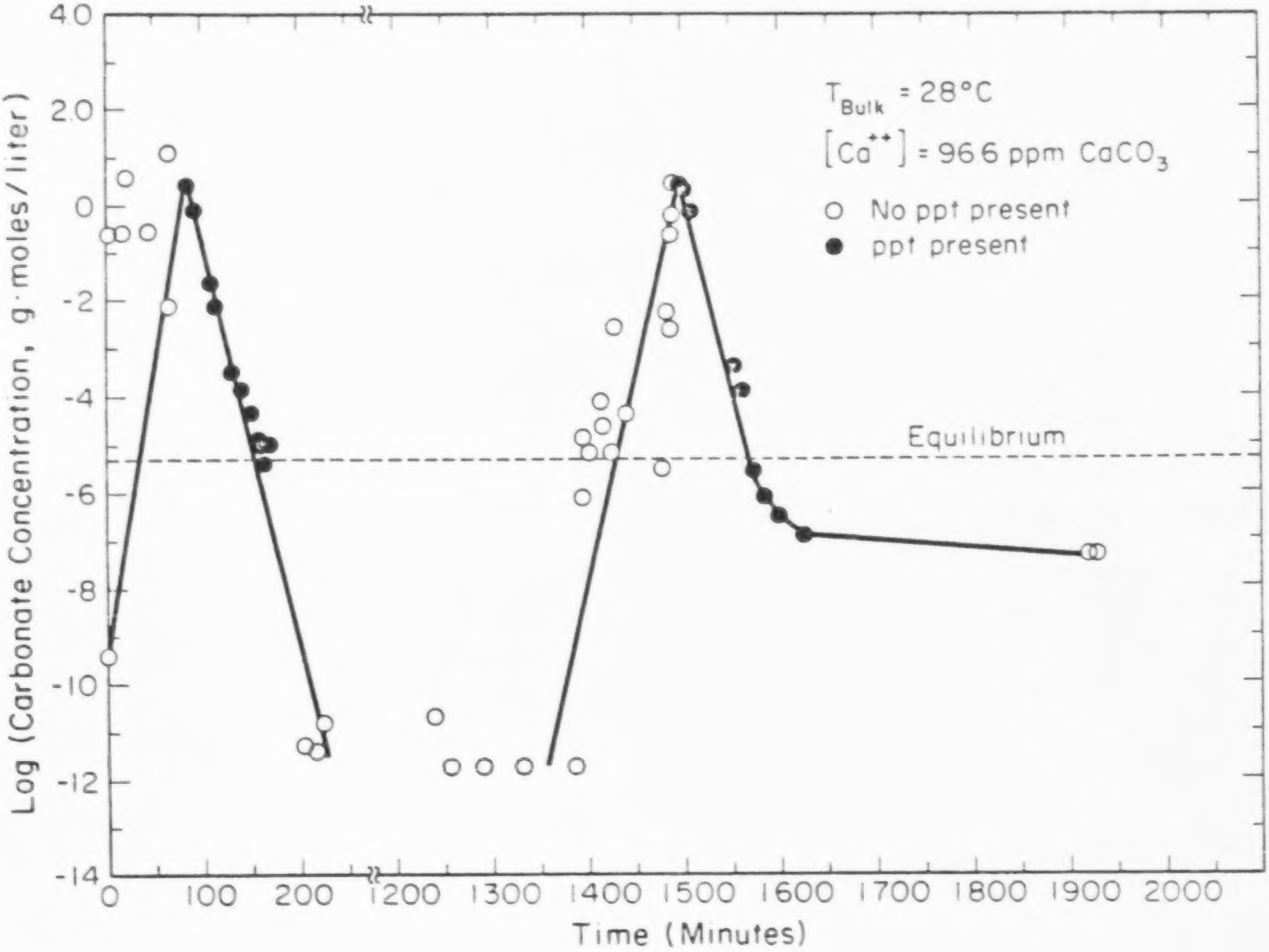

Figure 4. Repeated $CaCO_3$ Precipitation and Dissolution Induced by pH Adjustment and Control of CO_2 Pressure. (Run No. 23.)

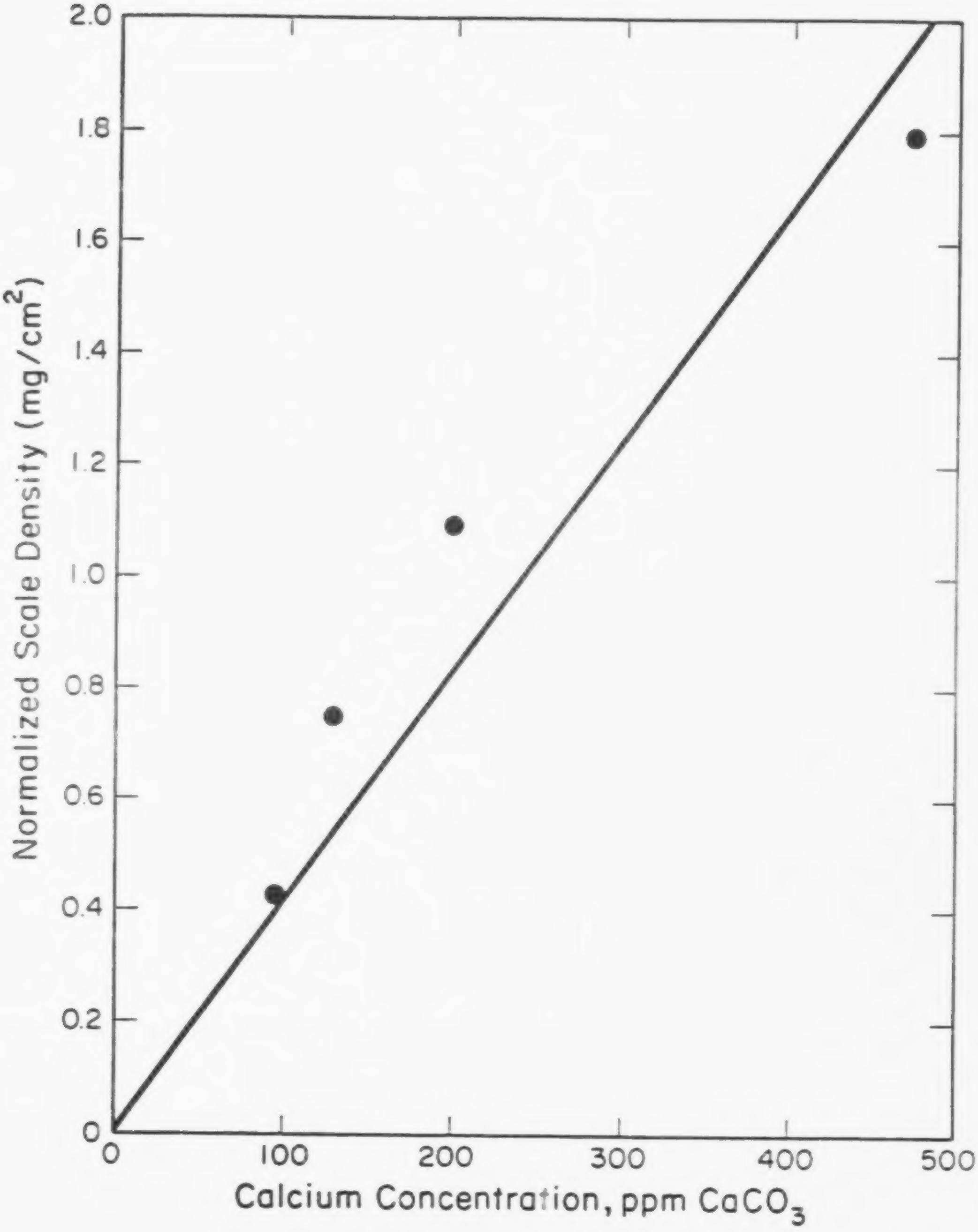

Figure 5. Normalized Scale Densities after Ten Hours Exposure at a Degree of Supersaturation of Twenty.

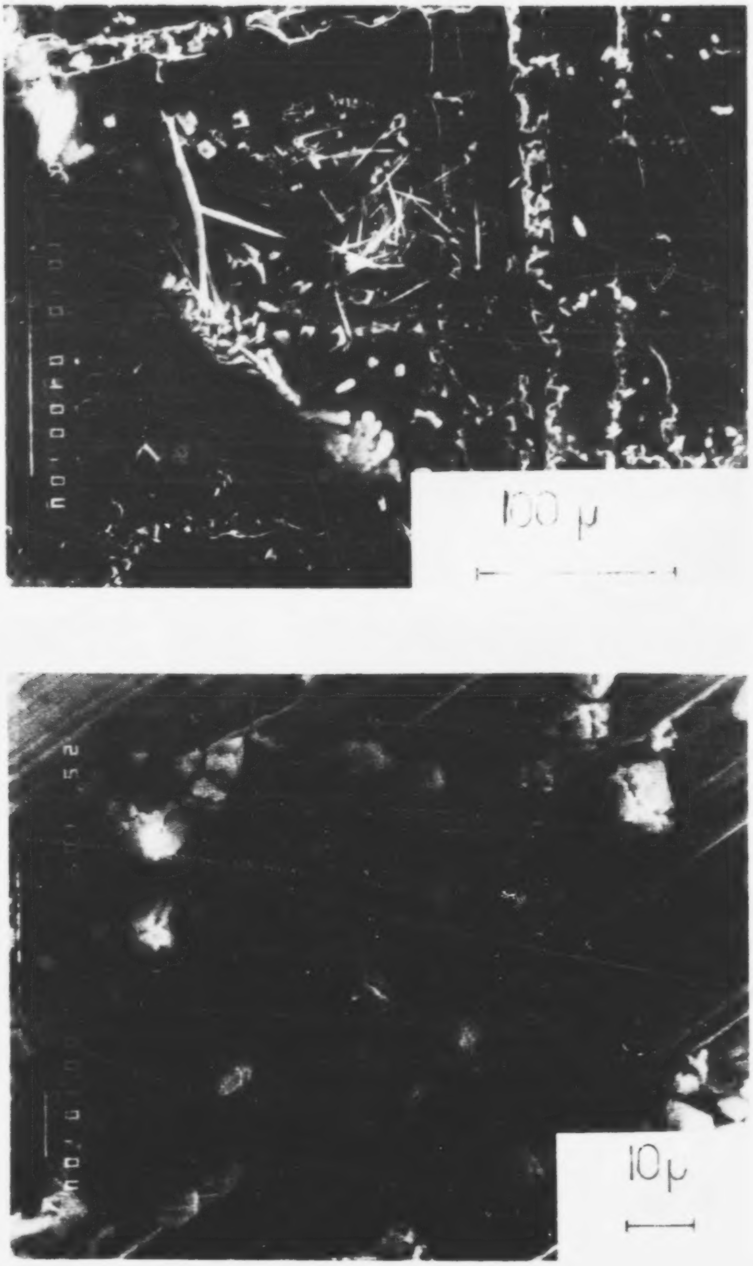

Figure 6. The Appearance of Both Equiax and Acicular Calcite on Stainless Steel.

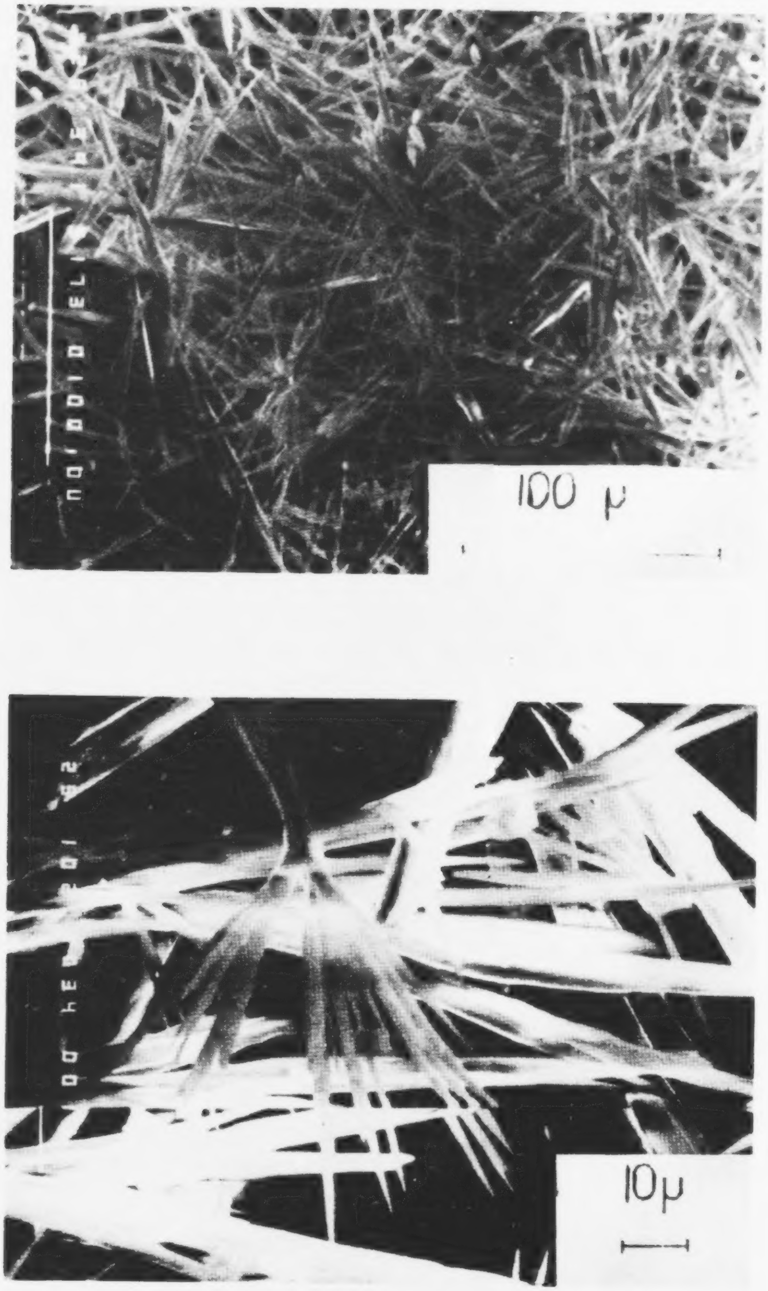

Figure 7. Typical Appearance of Acicular Calcite Formed on Stainless Steel.

Section 3: SOLID WASTE POLLUTION ABATEMENT

Chairman: Eugene F. Meyer, Chemist
Hazardous Waste Management Branch
Region V, EPA
Chicago, IL

ABSTRACT

FEDERAL REQUIREMENTS FOR CHEMICAL WASTE DISPOSAL

By

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Subtitle C of the Resource Conservation and Recovery Act (RCRA) of 1976 gives the U.S. Environmental Protection Agency the mandate to provide a regulatory program in the area of hazardous waste management and other areas of solid waste management. In response to this mandate, the U.S. EPA published on December 18, 1978, its proposed guidelines and regulations for the identification and listing of hazardous waste. This document, published in the Federal Register, is expected to be promulgated in 1980. Its various sections will be discussed, specifically with regard to the definition of a hazardous waste (Section 3001), its generation (Section 3002), transportation (Section 3003), and treatment, storage, and disposal (Section 3004).

RTI/1603/24-03S September 1979

ENVIRONMENTAL AND RESOURCE CONSERVATION CONSIDERATIONS OF STEEL INDUSTRY SOLID WASTE

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ABSTRACT

The United States steel industry produces roughly 137 million metric tons of solid waste annually (including in-plant mill scrap) and currently reuses or recycles about 80 percent. The balance, about 30 million metric tons, is characterized here as to origin, nature, and quantity. Current disposal methods and leachate characteristics of each type of waste are also described. The impact of Section 4004 of the Resource Conservation and Recovery Act is discussed with respect to solid wastes not classified as hazardous. This impact is to require the solid waste disposer to prevent groundwater endangerment from the migration of leachate. Assuming this is accomplished through the use of lined landfills, the incremental cost of Section 4004 to the industry is estimated as 21 million dollars per year. This represents a 40 percent increase in current disposal costs, but it is less than 2 percent of the current environmental expenditures.

ENVIRONMENTAL AND RESOURCE CONSERVATION CONSIDERATIONS OF STEEL INDUSTRY SOLID WASTE

1.0 INTRODUCTION

The iron and steel industry produces an estimated 137 million metric tons of waste (including metallic scrap) annually in the production of 125 million metric tons of steel. Approximately 80 percent of this waste is currently reused or recycled. This study examines the remaining 20 percent with respect to the impact of Section 4004 of the Resource Conservation and Recovery Act of 1976 (RCRA), based upon proposed criteria published in the February 6, 1978 issue of the Federal Register.

The approach taken to determine this impact was to:

(1) characterize the solid wastes as to origin, nature, quantity, and potential for groundwater endangerment,

(2) examine current disposal practices,

(3) outline the potential requirements of proposed Section 4004 criteria, and

(4) estimate the cost of meeting these potential requirements.

2.0 WASTE CHARACTERIZATION

2.1 Coke Plant Wastes

The solid wastes generated in the coke plant, including by-product recovery, are coke breeze, sludge from the tar decanter, lime sludge from the ammonia still, sludge from the biological treatment plant, and waste sludge from the light oil wash and neutralization. Breeze generally has several uses, although it can become an occasional disposal or stockpiling problem. The tar decanter sludge, lime sludge, and oleum wash sludge are classified hazardous, so they are subject to the criteria for disposal of hazardous wastes. An estimated 1.8 million tons of breeze and 140,000 tons of sludges are generated annually from the production of 48 million metric tons of coke.

2.2 Slags

There are two types of slag wastes: ironmaking and steelmaking. A typical analysis of blast furnace slag is 41 percent CaO, 35 percent SiO_2, 13 percent Al_2O_3, and 8 percent MgO with a basicity ratio of 1.0.[1] There is a wide variation in the range of compositions for steelmaking slag. The nature of the slag varies depending upon the metallurgy of the process involved, upon the impurities in the feed materials, principally sulfur, and upon the end product. BOF slag samples from two different steel companies contained 32-42 percent CaO, 15-30 percent FeO, 9-23 percent SiO_2, 5-10 percent MgO, and 0.1-0.2 percent Al_2O_3.[2] The slag basicity ratio ranged from 2 to 4.

Blast furnace slag is processed at 66 major slag plants and is sold as three general types: air-cooled, granulated, and expanded. Approximately 10 percent of the blast furnace slag that is produced is landfilled (Table 1); however, even in these cases it may serve a constructive purpose. For example, one major plant is using its slag as on-site fill material for future plant expansion. Other plants pile the slag in mounds for future sale or use it to dike a landfill area. Some old slag dump sites are being mined to recover the slag to meet the increased demand.

Steelmaking slag is processed at 35 major plants but in much smaller quantities than ironmaking slag. Steelmaking slag is sometimes recycled to the blast furnace to recover iron, manganese, and lime values, and finds some use in construction for unconfined bases, fill, and highway shoulders. Its utility is much more limited than ironmaking slag because it can undergo uncontrolled expansion due to hydration of free lime.[3] An estimated 45 percent of the steelmaking slag is used or recycled; the remaining 55 percent is landfilled. The landfilled slag often is used for dikes, landfill bases, and for layering or mixing with dust and sludge.

The amount of "stocked" slag was not estimated due to the difficulty in determining the difference in landfilling (or dumping) and stockpiling. Many disposal sites described as stockpiles have accumulated large quantities of slag over a period of years. A report prepared in 1976 for the Federal Highway Administration to examine the availability of wastes for use as highway materials estimated the quantities available at a few selected slag dump sites. There were six locations in Pennsylvania in 1976 that had 93.5 million tonnes (103 million tons) in slag piles.[4]

Table 1. SLAG DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR (TONNES PER YEAR)

Source	Generated	Landfilled	%	Recycled, Used	%
Ironmaking	28,300,000	2,800,000	10	25,500,000	90
Steelmaking	19,360,000	10,560,000	55	8,800,000	45
TOTAL	47,660,000	13,350,000	28	34,300,000	72

2.3 Iron Oxide Wastes

The iron oxide wastes include dusts, sludges, and scale generated by a variety of processes. Within each of these waste types are variations in composition, particle size, water content, and contaminants. Each presents its own problems, or lack of them, with respect to the potential for recycle or reuse. Steelmaking dusts and sludges are particularly troublesome due to many problems associated with recycle. A few of the key ones are:

(1) Zinc and lead in the dust are carried into the sinter and from there to the blast furnace, where they interfere with flue operations of the blast furnace and cause premature destruction of the furnace lining.

(2) The very fine particulates cause handling problems and interfere with smooth operations of the sintering process.

(3) The iron content of steelmaking fines is usually small although often highly variable.

(4) The tonnage of waste iron oxide generated in a single steelmaking facility may be too small to economically support a sophisticated and technically correct process for recovering the waste and converting it to a useful form.

2.3.1 Dust Treatment and Disposal. Dust is collected by dry air pollution control equipment used in the sinter plant, blast furnace, and steelmaking furnaces (Table 2). Sinter and blast furnace dusts are generally recycled, but steelmaking dust is mostly landfilled and accounts for 73 percent of the 1.2 million tonnes of dust which are not recycled.

Dust disposition data, available from 17 major plants, revealed that 16 practiced recycle, 6 had stockpiles on-site, and 7 landfilled a portion of their dust.

Some specific dust handling techniques include:

(1) mixing with scale and stockpiling,

(2) mixing with water to prevent wind transportation and placing in a holding pond,

(3) recycling BOF dust by using select scrap in the BOF to keep zinc content down,

Table 2. DUST DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR (TONNES PER YEAR)

Source	Generated	Landfilled	%	Stocked	%	Recycled	%
Sinter	740,000	40,000	6	---	--	700,000	94
Ironmaking	1,290,000	170,000	13	120,000	9	1,000,000	78
Steelmaking	1,050,000	690,000	66	190,000	18	170,000	16
TOTAL	3,080,000	900,000	29	310,000	10	1,870,000	61

(4) "storing" dust in the ground by covering with a layer of dirt, and covering with BOF slag.

2.3.2 Sludge Treatment and Disposal. Sludge is generated by water treatment facilities in which solids are removed from process wastewater and from the water used in wet pollution control equipment. The wastewater goes through a series of treatments that may include settlers, thickners, oil skimmers, scale pits, polymer addition to aid settling and dewatering, clarifiers, filters and biological treatment. The type of treatment is plant specific and may involve almost any combination of the above for treating water from various processes individually or in central treatment plants. The resulting sludge is recycled, landfilled, stocked, or put into a lagoon for additional dewatering before disposal. The use of lagoons and holding ponds is widespread with each major plant having at least one such facility. A total of 16 lagoons and ponds were identified in 13 major plants, and each plant generated some sludge that was landfilled.

Complete sludge disposition data was available from 17 plants. These data indicated that 13 plants practiced recycling, 10 had stockpiles on-site for potential reuse, and all 17 landfilled at least a portion of their sludge (Table 3). Sludge from the rolling mills and steelmaking furnaces accounts for 1.3 million tonnes of the estimated 1.6 million tonnes of sludge landfilled yearly.

Some of the disposal techniques used by individual plants include:

(1) mixing with dust and slag in landfill,
(2) spreading over slag pile,
(3) mixing with dust and scale on site,
(4) placing in pits in the landfill area, then covering with slag, and
(5) placing in lined landfill with leachate collection.

2.3.3 Scale Treatment and Disposal. Scale is generated in the rolling operations and is usually collected in scale pits or settling basins. These settlers serve as a preliminary treatment of direct contact process water that is used for cooling, scale removal, and flushing. The heavy coarse pieces settle out and the very fine scale is removed in subsequent water treatment as a sludge.

Table 3. SLUDGE DISPOSITION FROM 125,000,000 TONNES OF STEEL PER YEAR (TONNES PER YEAR)

Source	Generated	Landfilled	%	Stocked	%	Recycled	%
Ironmaking	2,030,000	270,000	13	190,000	9	1,570,000	78
Steelmaking	1,170,000	617,000	53	286,000	24	267,000	23
Rolling Mills	758,000	730,000	96	---	--	28,000	4
TOTAL	3,958,000	1,617,000	41	476,000	12	1,865,000	47

Most of the scale generated in the rolling mills is recycled or stocked for potential recycling. Some of the stockpiled scale is not recycled immediately due to a high oil content that causes problems of hydrocarbon emissions and fouling of fabric filters in the sinter plant. Approximately 70 percent of the mill scale (3.9 million tonnes) is recycled, 30 percent stocked, and a small quantity is dumped. That portion disposed of in a landfill is generated by the cold rolling operation and has a high oil content, but it is only 0.04 percent of the mill scale produced.

Soaking pit scale, also called soaking pit slag, is iron oxide scale fused with the coke breeze or dolomite that has been placed in the bottom of the soaking pit. This scale may be contaminated with refractory or other material. An estimated 1.3 million tonnes of soaking pit scale are landfilled annually.

2.4 Miscellaneous Waste Treatment and Disposal

Plant debris, trash, rubble, and refractory from relining of furnaces are landfilled. AISI estimated that these wastes are generated at a rate of 10 percent of the steel produced (200 pounds per ton), so that a national production of 125 million tonnes of steel would give 12.5 million tonnes of this waste.[5] Eight plants reported to state agencies regarding the disposition of miscellaneous debris and the quantities totaled approximately 5 percent of the steel produced. In three cases the waste was disposed of by means of contract disposal, in another three at an off-site landfill, and in two at an on-site landfill.

Fly ash and bottom ash (or clinker) are solid wastes generated in coal-fired boilers. An estimated 380,000 tonnes are generated annually by the iron and steel industry. Information on these wastes was obtained from state agencies for six plants and their rate of generation was approximately 13 kg per tonne of steel. Two of these plants landfilled the ash on-site and the other four off-site.

The sludge from neutralization of spent pickle liquor was estimated as 350,000 (dry) tonnes per year.[6] An EPA survey of 16 plants revealed that 60.8 percent of the waste pickle liquor was disposed of untreated by deep-well injection, dumping on a slag pile, or direct discharge; 20.5 percent was neutralized on-site; 11.3 percent handled by contract hauler; and 7.4 percent was recycled, regenerated, or reused. The disposal problem is complicated by the fact that hydrated metal oxides from the neutralization process usually will not dewater to more than 10-20 percent solids, so this sludge is not really a solid but a gelatinous fluid. The pickling of one millions tons of steel could result in 200,000 tons of wet sludge, which would require 150 acre-feet of permanent fill volume.[7] A change from deep-well disposal to neutralization would, therefore, cause a significant increase in the amount of sludge that must be disposed of in landfills.

In Pennsylvania, most pickle liquor is handled by two contract haulers who use the following disposal technique:[8]

1. Pickle liquor is placed in a lagoon and neutralized;
2. The liquid is floated off and the sludge is left in place in the lagoon, and
3. When the lagoon is full, it is covered with a sloping top of soil and revegetated.

2.5 Summary of Waste Generation

The nature of a specific waste generated may vary widely from plant to plant in both composition and quantity.[6,9] Some typical variations are shown in Table 4; the quantities are based upon a plant producing 2.5 million metric tons of steel per year. Compositions vary as widely as quantity. For example, blast furnace dust may range from 5.9 to 54 percent iron, and BOF sludge has varied from 32 to 66 percent iron, or 0.3 to 13 percent zinc.

A summary of the waste generation (Table 5) shows that 78 percent of the 138 million tons of solid waste is recycled or reused. Slag is the predominant landfilled waste at 13.4 million tons of the 30.5 million tonne total. The miscellaneous wastes include metallic scrap, rubble and debris, pickle liquor sludge, fly ash, and bottom ash.

3.0 CURRENT DISPOSAL FACILITIES

3.1 Prevalence of Types of Disposal Practices

Published data were reviewed and supplemented with data from state agencies to obtain estimates of the number of disposal sites and percentages of wastes disposed of on-site, off-site, and by contract disposal. The data base for the

Table 4. VARIATIONS IN WASTE GENERATION QUANTITIES[6,7] (BASIS = 2,500,000 TONNES STEEL/YR)

	Quantity of Waste, tonnes/yr		
Waste	Minimum	RTI Estimate	Maximum
Coke Breeze	17,300	32,400	45,000
Still Lime Sludge	315	540	540
EAF Slag	25,000	60,000	164,500
EAF Dust	2,925	6,500	8,000
BOF Slag	230,000	290,000	400,000
Blast Furnace Slag	345,600	556,800	820,800
Blast Furnace Dust	11,200	25,360	54,500
Blast Furnace Sludge	3,200	40,000	44,800

Table 5. SUMMARY OF WASTE GENERATION FOR 125 MILLION TONNES OF STEEL PER YEAR (MILLIONS OF TONNES PER YEAR)

Waste	Generated	Landfilled	%	Recycled, Used, or Stockpiled	%
Coke Plant	1.9	.1	(7)	1.8	(93)
Slag	47.7	13.4	(28)	34.3	(72)
Dust	3.1	.9	(29)	2.2	(71)
Sludge	4.0	1.6	(41)	2.4	(59)
Scale	6.9	1.3	(19)	5.6	(81)
Miscellaneous	74	13.2	(18)	60.8	(82)
TOTAL	137.6	30.5	(22)	107.1	(78)

prevalence of different types of sites consisted of the 13 plants visited by Dravo[6] and Calspan[9] and 20 plants for which information was provided by state agencies in Pennsylvania, Indiana, Maryland, Michigan, and Ohio. The various disposal facilities for the 33 plants included 28 on-site, 11 off-site, and 10 contract disposal sites. The total for contract disposal does not include slag processors or those contractors handling spent pickle liquor only.

The use of on-site landfills appears to be a function of plant location and land availability. For example, a company in the Pittsburgh area has one large off-site landfill serving four plants, while in eastern Pennsylvania a large plant has five landfills on its own property.

Contract disposal is used routinely in combination with on- or off-site disposal.[10] Based upon a sample of 10 contract haulers, the types of wastes eliminated via contract disposal (excluding slag, oil, pickle liquor) were plant rubble, debris, miscellaneous wastes (4), sludges (4), and soaking pit slag (2).

Complete data on the quantities of waste disposed of by each method were available for 17 plants. These quantities were summed and the percentage of total nonhazardous waste eliminated via each of the three disposal categories was estimated as 65 percent on-site, 29 percent off-site, and 6 percent by contract disposal.

3.2 Estimate of the Number of Major Landfills

To estimate the number of major landfill sites, it was necessary to establish the number of major iron and steelmaking plants. A review of the industry revealed that there were approximately 50 plants using blast furnaces, basic oxygen furnaces, or open hearths (often in combination with electric arc furnaces). In addition, 13 of the 103 plants using only EAF's have capacities exceeding 500,000 tonnes of steel per year and were arbitrarily included as major plants. The total of 63 major plants to be used as the basis for estimating the number of landfills account for more than 90 percent of steel production (Table 6). The estimate of major landfill sites for these plants included 53 on-site, 21 off-site, and 19 off-site landfills belonging to contract haulers.

Table 6. ESTIMATE OF MAJOR LANDFILLS

	Data Base	Estimate for Total
No. of Major Plants	33	63
On-Site	28	53
Off-Site	11	21
TOTAL	39	74
Contract Disposal*	10	19

*Excludes slag, pickle liquor, and waste oil processors

4.0 IMPACT OF SECTION 4004 OF RCRA

Section 4004 of the Resource Conservation and Recovery Act of 1976 (RCRA) provides for the promulgation of regulations containing criteria for determining whether solid waste disposal facilities should be classified as sanitary landfills or open dumps. The establishment of open dumps is prohibited, so future sites must meet the criteria that define a sanitary landfill. At a minimum, a facility may be classified as a sanitary landfill only if there is no reasonable probability of adverse effects on health or the environment from the disposal of solid waste there.[11]

Proposed classification criteria for solid waste disposal facilities were published in the Federal Register on February 6, 1978.[12] The major impact on current disposal practices is to require that the quality of the groundwater beyond the disposal facility's property boundary is not endangered. Endangerment is defined as the introduction of any substance into the groundwater in such a concentration that additional treatment is necessary for a current or future user of the water, or otherwise makes the water unfit for human consumption.[12] Maximum contaminant levels are set forth in promulgated National Interim Primary Drinking Water Standards.[13,14]

Table 7 lists various permissible criteria of selected leachate components in drinking water. Contamination beyond these limits makes the water undesirable for human consumption. Organic leachate components are also of concern because certain coke plant wastes are known to contain polycyclic aromatic hydrocarbons. National standards for suspected carcinogens such as polycyclic aromatic hydrocarbons have not been promulgated due to a lack of information about health effects. Specific organic compounds which are currently monitored have been selected on the basis of the likelihood of occurrence in treated water, the toxicity data, and availability of practical analytical methods. EPA is actively investigating suspected carcinogens and future water standards may reflect this activity. The World Health Organization drinking water standards permit only 0.0002 mg/ℓ of polynuclear aromatic hydrocarbons.[15]

4.1 Water Extraction of Solid Waste Materials

Water extraction tests were reported by six plants to the Pennsylvania Department of Environmental Research as well as from an EPA survey[16] and ASTM.[17] These tests differ from the proposed EPA Extraction Procedure in that distilled

Table 7. PERMISSIBLE CRITERIA FOR SELECTED COMPONENTS FOR PUBLIC WATER SUPPLIES

Constituent	Permissible Criteria (mg/ℓ)
pH	6.0-8.5[b]
Arsenic	0.05[a,b]
Barium	1.0[a,b]
Cadmium	0.010[a,b]
Chromium	0.05[a,b]
Fluoride	1.2 (63.9-70.6°F)[b]
Iron (filterable)	0.3[b]
Lead	0.05[a,b]
Manganese (filterable)	0.05[b]
Selenium	0.01[a,b]
Silver	0.05[a,b]
Total dissolved solids	500.0[b]
Zinc	5.0[b]
Carbon chloroform extract	0.15[b]
Cyanide	0.2[b]
Oil and grease	Virtually absent[b]
Phenols	0.001[b]
Mercury	0.002[a]

[a] National Interim Primary Drinking Water regulations[13]

[b] Water Quality Criteria, Department of Interior, FWPCA[14]

water was used, whereas the proposed EPA procedure uses a limited amount of acetic acid for pH control. The ASTM leachate values were reported by Enviro Control with additional ASTM testing provided by AISI. Although ASTM tested the wastes with several different types of water, only the 48 hour extraction with carbon dioxide saturated reagent water is included in this study.

Water extraction testing provides a common basis for comparing the potential of various wastes to endanger the groundwater. It also provides a basis for predicting which components may appear in leachate. It does not predict natural leachate composition, since this is affected by many site specific factors. Even within a single site, natural leachate composition varies and at times may exceed the levels of a simple water extract.

4.1.1 Coke Plant Wastes. Coke plant wastes include coke breeze, tar sludges, and pitches from various tar storage and processing operations, ammonia still lime sludge, and biological treatment sludge. Due to the widely diverse processes which can be used to treat the coke by-product gases, the number of wastes, the amounts generated, and even the composition are expected to vary from plant to plant. In general, coke plant wastes are expected to be hazardous with the possible exception of coke breeze.

With the exception of pH, the water extract results are best expressed as the ratio of the amount of material in the extract divided by the permissible criteria (i.e., number of times drinking water standards). The permissible criterion, used was the largest concentration presented in the Drinking Water Standards. This criterion, which may differ from some legal requirements, is used to provide a uniform method for assessing potential aesthetic and health impacts from leachate, and is not used for the classification of a waste as hazardous.

The tar decanter sludge extract contains relatively large amounts of oil and grease as well as phenols (Table 8). Ammonia still lime sludge extracts contains cyanides, phenols, and may contain polycyclic aromatic hydrocarbons in concentrations high enough to be of concern. The water extract from cooler sludge contained relatively large amounts of oil and phenols. Some tar is also expected in the oil from the extract. In general, coke plant wastes should be given special consideration because of the carcinogenic nature of the coke oven gas from which they originate and the potential of phenols and cyanides to endanger the groundwater. Most coke plant solid wastes are hazardous and should be segregated from nonhazardous wastes.

Table 8. RESULTS OF AQUEOUS EXTRACTION TESTS OF COKE PLANT WASTES. (Results are expressed in the amount detected divided by the permissible criteria. No analysis designated X.)

	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Tar Decanter Sludge	8.9	1320.0	5×10^5	3.0	X	<0.2	< 4.0
	7.8	60.0	1.3×10^5	<0.04	<3.2	<3.7	9.6
Ammonia Still Lime Sludge	11.5	X	2×10^4	990.0	X	0.4	10.0
Cooler Sludge	6.7	60.0	12×10^5	0.2	<4.0	<2.2	<10.2
Coke Breeze, Mine Refuse	10.4	33.0	0.0	0.0	0.0	0.0	0.0

4.1.2 Slags. Slags are the major solid waste generated by the iron and steel industry. The results of aqueous extraction tests for various iron and steelmaking slags indicate that steelmaking slags are generally of more environmental concern than the blast furnace slag (Table 9). For example, the pH of leachate from steelmaking slags is much higher than that from blast furnace slag and may be as high as 12.5. Other leachate components of possible concern are chromium, lead, and phenols.

4.1.3 Dusts and Sludges. Water extraction tests performed on sludges (Table 10) are somewhat incomplete, but show the presence of cadmium, chromium, and lead. Oil, phenols, and cyanides were found in blast furnace sludge. Results from dusts (Table 11) similarly show these three metals and oil, phenol, and cyanides.

4.1.4 Miscellaneous Wastes. Many miscellaneous wastes were tested and showed varying levels of cadmium, chromium, lead, oil and phenols. These wastes include melt shop rubble, mill scale, soaking pit slag, wastewater sludge, lagoon sludge, and acid rinse sludge.

4.2 General Information on Soil Attenuation and Leachate Movement

Water extraction results of steel wastes that are used to estimate leachate composition were just discussed. However, for the purpose of assessing the impact of leachate on the environment, it is important to understand the mechanisms that may alter the leachate and the factors that affect the accurate measurement of this impact on groundwater.

As leachate moves through subsurface soils, several mechanisms can affect the nature and, consequently, the environmental impact of the leachate. These include ion exchange and adsorption by clay and organic soils, metal fixation, and reactions of metal cations to yield a precipitate of low solubility.[18] Heavy metals in their metallic state are generally insoluble, but the heavy metal salts (as from electroplating or pickling), may be quite soluble. Ammonia that is present in leachate is oxidized to nitrate under aerobic conditions by certain bacteria and may be nitrate by the time it reaches groundwater.

The fate of organic leachate constituents is not well documented since few have been identified and their toxicity is unknown. Organics may come

Table 9. RESULTS OF AQUEOUS EXTRACTION TESTS OF BOF SLAG. (Results are expressed in amount detected divided by permissible criteria. No analysis designated X.)

Material	Source	Solids	Oil	Cd	Cr	pH (units)	Pb	Phenol
BOF Slag	A	2.2	27	<3.2	<3.7	12.2	< 4.4	<23
	E	0.3	X	<2.0	<1.0	12.5	7.0	<26
	F	0.7	30	0.0	4.2	9.4	0.0	0.0
	C	X	X	X	3.0	12.5	4.0	X
	D	X	X	<1.0	<1.0	9-11	<0.2-1.6	X
	D	1.4	X	<1.0	<0.2	9.0	1.2	X
	D	1.3	X	X	X	12.4	X	X

Table 10. RESULTS OF AQUEOUS SOLUBILITY TESTS OF IRON AND STEEL SLUDGES. (Results are expressed in amount detected divided by the permissible criteria. No analysis designated X.)

Material	Source	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Blast Furnace Sludge	A	9.5	67.0	14.0	25.0	3.2	3.34	4.0
	C	9.5	X	400.0	X	X	0.4	4.0
BOF Sludge	G	9.6	X	X	X	X	3.6	X
	C	10.4	X	X	X	X	1.8	4.0
Open Hearth Sludge	D	5.4-6.9	X	X	X	1.0	1.0	1.0-2.0
EAF Sludge	C	11.5	X	X	X	X	1880.0	40.0

Table 11. RESULTS OF AQUEOUS SOLUBILITY TESTS OF IRON AND STEEL DUSTS. (Results are expressed in amount detected divided by the permissible criteria. No analysis designated X.)

Material	Source	Solids	pH (units)	Oil	Phenols	Cyanides	Cd	Cr	Pb
Blast Furnace Dust	A	X	11.7	X	250	<1.5	X	0.6	5.0
Open Hearth Dust	D	X	6.3-7.2	X	X	0.02-0.4	63-360	0-1.0	12-30
	D	19.0	6.8	X	X	X	330	0.0	66.0
EAF Dust	C	X	12.6	X	X	X	X	6.8	3000
	G	15.0	7.0	13.0	0	4.2	353	25,000	6.0
BOF Dust									
Precipitator	A	8.0	12.4	53.0	28.0	0.4	<3.2	<37.4	<4.4
Baghouse	A	10.4	8.2	20.0	40.0	0.03	<3.2	9.52	8.2
	E	0.8	12.5	X	X	X	X	2.0	142

directly from the solid waste or from decomposition products and are probably subjected to adsorption and microbial degradation.[19]

These mechanisms are described to show the fate of some leachate constituents and not as a means of groundwater protection. They are often unpredictable in their effect, and once the soil capacity for a particular mechanism has been exceeded, a constituent may have an unobstructed path to the groundwater.

Groundwater travels at low velocities, typically 1.5 meters/year to 1.5 meters/day. This low velocity results in laminar flow which exhibits mixing characteristics different from the turbulent flow usually associated with surface water. When water with a composition different from the groundwater is injected or percolated into the groundwater, it tends to maintain its integrity and is not diluted with the entire body of groundwater. Instead, it moves with the groundwater flow as a plume undergoing minimal mixing.[19]

Some other factors that affect leachate movement and consequently affect monitoring and sampling requirements for environmental assessment:

1. Geohydrologic conditions: Under some circumstances leachate will percolate rapidly, as through coastal plains sand, or through channels that may have developed in limestone. In other cases, it may move only a few feet per year through soils of low permeability.
2. Climatic conditions: Leachate will move differently depending on whether or not the soil is frozen, the amount of annual precipitation, and frequency of brief periods of intense rainfall in a dry climate.
3. Disposal methods: The type of disposal method, whether lagoon, pit, dump, or landfill and the site preparation affect the rate of leaching.
4. Type of wastes: Some important waste types are (a) solid, sludge, or liquid (as in a lagoon with a continuous leachate plume), (b) organic or inorganic, and (c) water soluble or insoluble.
5. Age of site: This is relevant in that leachate percolation may take several months to reach the groundwater.
6. Miscellaneous: The influence of nearby wells, changes in aquifer depth, and groundwater velocity also affect leachate migration.

4.3 Groundwater Analysis From Iron and Steel Landfills

Groundwater analyses were provided to the Pennsylvania Department of Environmental Resources by several iron and steel companies in Pennsylvania

(Table 12). When these results are compared with the leachate from individual wastes, both the ground water and leachate extract contain large quantities of oil and grease. The problems with the water in meeting drinking water standards include alkalinity (high pH), excessive dissolved solids, and significant amounts of chromium and manganese. The overall quality of the groundwater was difficult to assess because of the lack of testing for heavy metals such as cadmium, and for specific organic materials in the extracts.

Five groundwater samples were provided by two steel companies for additional testing at RTI. The samples showed high levels of manganese with respect to drinking water standards. Other elements for which maximum levels have been set were generally within drinking water standards. Analysis for polynuclear aromatic hydrocarbons (PNA) showed levels of 3 to 30 parts per billion (ppb). Although no national standards for PNA's have been established, this level is 15 to 150 times the International Standards for Drinking Water of 0.2 ppb.

4.4 Cost of Proposed Section 4004 RCRA Criteria

The Resource Conservation and Recovery Act provides for the promulgation of regulations and criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified as open dumps. The general current practice in the iron and steel industry is the dumping of wastes in unlined sites. The major impact of the proposed criteria is to require the disposer to control the leachate migrating toward the groundwater.

All steel plant waste, with the possible exception of bricks, rubble, and certain trash items are anticipated to have leachate which could make groundwater unfit for human consumption. Contaminants such as oil and grease, dissolved solids, fluorine, chromium, manganese, lead, iron, phenol, cyanide, cadmium, zinc, and mercury have been identified in the water extracts of some of the various iron and steel wastes at concentrations that may endanger groundwater.

Although most steel plant wastes are not currently classified as hazardous, available leachate and/or water extraction test data have shown the potential for the extract to make groundwater unfit for human consumption. In view of these facts and in evaluation of environmental endangerment, a lined landfill may be required for these wastes. A major economic impact may result if

Table 12. **SELECTED LEACHATE COMPONENTS IN THE GROUNDWATER OF VARIOUS IRON AND STELL WASTE LANDFILLS.** (Results expressed in amount measured divided by permissible criteria. No Analysis designated X.)

Site, Sample Position	Solids	Oil	pH (units)	Ammonia	Cr	Mn	Phenols	Cd
A,1	4.5	206.0	7.5	0.1	0.8	54.0	<12.0	X
A,6	6.3	120.0	7.5	0.1	2.6	117.0	<13.0	X
B,3	5.4	120.0	12.1	4.5	0.8	2.2	<10.0	X
C,1	1.6	0.53	11.4	X	X	X	4.9	<2000
D,1	X	81.0	12.2	1.8	0.4	0.0	X	X
E,2	X	22.5	X	X	0.6	10.0	X	0.0

contaminants must be removed from the collected leachate. However, since the wastes are not classified hazardous, the leachate disposal method assumed for these wastes is controlled discharge to waterways or recycle back through the landfill.

Discarded steelmaking slag could need liners because of the high pH of the water extract, the dissolved solids in the extract, and inorganic elements. However, the slag does not require lined landfilling if it is used as a salable product, for resource recovery, or if the state has exempted the disposal area from groundwater requirements under Case 2 of the proposed rules. Since steelmaking slags are a major landfilled waste, two calculations were performed on the economic impact of the proposed criteria with and without the required lined landfilling of steel slag.

The impact of the proposed Section 4004 criteria on the iron and steel industry was calculated assuming the following: the criteria requires the lined landfilling of certain wastes, the removal of the leachate resulting from rainfall on these wastes, and the controlled discharge of the water which is collected. Therefore, the cost of the criteria would be the cost of converting an existing landfill into an area for the collection and removal of leachate and would require a substantial capital investment. The criteria do not specifically require changes in current solid waste disposal practices such as the transportation of wastes, employment of landfill personnel, or purchase of land for waste disposal. It should be pointed out that the costs of these criteria do not include those costs incurred as a result of hazardous waste disposal, which may be more expensive than for nonhazardous wastes. The elements considered in determining the additional cost include a hydrogeologic survey, excavation, lining the landfill, leachate collection, and groundwater monitoring.

The estimated annual capital cost of lining nonhazardous waste landfills is $6.9 million (Table 13). The cost of a lined landfill for steel slag disposal is approximately twice that of nonslag nonhazardous waste disposal. Although some economies of scale are achieved with increasing waste disposal volume, when steel slag is placed in a lined landfill, the overall cost is still three times as high. The estimated cost is relatively low for two major reasons, primarily because only the cost of converting a potential landfill site to a lined landfill was considered, and secondarily because the majority

Table 13. SUMMARY OF ESTIMATED 4004 CRITERIA COSTS

Enforcement	Annual Capital Cost ($ Millions)	% Current Environmental Costs	% Future Environmental Costs	% of Sales	% of Current Disposal Costs
A-Steel Slags Excluded	6.9	0.6	0.2	0.01	12
B-Steel Slags Included	21.1	1.9	0.6	0.04	37

of iron and steel wastes are currently either recycled, sold, or used in a manner consistent with the objectives of RCRA.

Current disposal costs are estimated for 30 million tonnes of nonhazardous waste at an average cost of $1.90 per tonne or $57 million. This represents a small fraction of current and future environmental costs. Current annual environmental operating costs were estimated as $8 per ton of steel, including the cost of air and water pollution control.[20] The long term total environmental costs, including disposal of nonhazardous solid waste, are estimated as $3,620 million per year.[21]

The proposed criteria for Section 4004 will have a major impact on the disposal practices used by the industry and substantially increase the cost of present land disposal systems. It is estimated that the capital costs for developing leachate collection facilities alone will double the disposal costs of those wastes placed in lined landfills.

4.5 Conclusions

Although most iron and steel wastes are not listed as hazardous, the available leachate testing data indicate that leachate control is needed to protect groundwater. Most of these wastes are currently deposited in facilities which do not provide for leachate collection. The major impact of the proposed RCRA criteria is to require the disposer to prevent groundwater endangerment from leachate migration. Assuming that this is accomplished by using a lined landfill with leachate collection, this will increase the industry's current disposal costs by 40 percent. However, this 40 percent increase represents less than 2 percent of the current environmental costs.

5.0 ACKNOWLEDGEMENTS

This study was jointly funded by the U.S. Environmental Protection Agency's Industrial Environmental Research Laboratory and the Office of Solid Waste. The guidance and direction of project officers John Ruppersberger, Jan Auerbach, and William Kline are gratefully acknowledged.

6.0 REFERENCES

1. McGannon, H. E., The Making, Shaping, and Treating of Steel, 9th Ed., Pittsburgh, U. S. Steel, 1971.

2. Slag Analyses from Wheeling-Pittsburgh and Allegheny-Ludlum, Pittsburgh Office, Pennsylvania Department of Environmental Resources, October 1978.

3. Evans, J. R. "Slag-Iron and Steel," Bureau of Mines Minerals Yearbook, U. S. Department of the Interior, 1976.

4. Collins, R. J. "Availability of Mining Wastes and Their Potential For Use as Highway Material," Federal Highway Administration, FHWA-RD-76-107, May 1976.

5. Personal Communication with E. Young, Solid Waste Committee, American Iron and Steel Institute, November 1978.

6. Pasztor, L. and S. B. Floyd, Jr., "Managing and Disposing of Residues from Environmental Control Facilities in the Steel Industry," U.S. Environmental Protection Agency, EPA 600/2-76-267, October 1976.

7. U. S. Environmental Protection Agency, "Development Document for Interim Final Effluent Limitations Guidelines and Proposed New Source Performance Standards for the Forming, Finishing, and Specialty Steel," EPA 440/1-76-048-b, March 1976.

8. Personal Communication with Mr. C. A. Duritsa, Pittsburgh Office, Pennsylvania Department of Environmental Resources, October 1978.

9. Leonard, R. P., "Assessment of Industrial Hazardous Waste Practices in the Smelting and Refining Industry," Vol. III, Ferrous Smelting and Refining, U. S. Environmental Protection Agency, EPA-SW 145 c.3, 1977.

10. Personal Communication with Edward C. Levy Co., Detroit, MI, October 1978.

11. Public Law 94-580, October 21, 1976. The Resource Conservation and Recovery Act of 1976.

12. Solid Waste Disposal Facilities, Proposed Classification Criteria, EPA, Federal Register, February 6, 1978, Part II.

13. National Interim Primary Drinking Water Regulations, EPA Federal Register, Vol. 40, No. 248-Wednesday, December 24, 1975.

14. Report of the National Technical Advisory Committee to the Secretary of the Interior, Water Quality Criteria, Federal Water Pollution Control Administration, Washington, D. C., April 1968.

15. International Standards for Drinking Water, 3rd Ed., WHO, Geneva, 1971.

16. Leonard, R. P., "Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry," Volume IV, U.S. Environmental Protection, EPA-SW 145 c.4, 1977.

17. Berney, B. W., "Hazardous Waste Listings: Fully Integrated Steel Mills." U. S. Environmental Protection Agency, May 1978.

18. Weant, George E. and M. R. Overcash, "Environmental Assessment of Steelmaking Furnace Dust Disposal Methods," U. S. Environmental Protection Agency, EPA 600/2-77-044, February 1977.

19. "Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities," U. S. Environmental Protection Agency, EPA 530/SW-611, August 1977.

20. "Prices and Costs in the United States Steel Industry," The Council on Wage and Price Stability, Washington, D.C., October 1977.

21. A. D. Little, Inc., "Steel and the Environment: A Cost Impact Analysis--A Report to the American Iron and Steel Institute." A.D.L., Inc., C-80527, May, 1978.

DEOILING AND UTILIZATION OF MILL SCALE

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ABSTRACT

Screening and deoiling of mill scale are necessary in order to recycle mill scale through a sinter plant which incorporates a baghouse without causing environmental and operational problems. The oil and moisture contents of the mill scale vary with its size and affect the screening operation. Without deoiling, oil on the mill scale volatilizes during sintering. As a result, the non-condensable hydrocarbons increase the opacity of the stack gases and the condensable hydrocarbons adversely affect the baghouse operation.

In view of the above, various mill scale deoiling methods were investigated which include both thermal and water washing techniques. Inland mill scale is currently being deoiled on a commercial basis in a direct-fired kiln. Finally, a comparison between oily and deoiled mill scale properties is made to determine the effect of deoiling on mill scale utilization in sintering and blast furnace operations.

DEOILING AND UTILIZATION OF MILL SCALE

INTRODUCTION

Inland Steel Company's No. 3 Sinter Plant commenced operation in 1959. The Dwight-Lloyd sinter strand is 2.44 m wide and 51.20 m long with a corresponding strand area of about 125 m^2. The strand has a design capacity of 3628 Mg/d of iron ore acid sinter. Over the past several years, super-fluxed sinter of ~3 basicity $[(CaO + MgO)/(Al_2O_3 + SiO_2)]$ has been produced from a mix containing iron ore, sinter flux, steelmaking slag, blast furnace flue dust, mill scale and burnt lime fines. In 1978, the sinter plant productivity averaged 3300 Mg/d of basic sinter. The sinter is consumed in the blast furnaces and accounts for about 15-25% of the iron-bearing burden; the balance is made up mostly of iron-oxide acid pellets with minor quantities of steelmaking slag.

In the sinter plant, the multiclones of the settling chamber, as well as the dry electrostatic precipitator, remove solid particulates from the strand off-gas. In addition, in order to comply with the stringent environmental regulations regarding solid dust emissions, a baghouse was installed in October, 1975, to treat the strand off-gas. A second baghouse treats the off-gas from the sinter breaker, hot screening and initial cooler zone at the sinter discharge end of the strand.

Due to the start-up of the mainstack baghouse, an earlier practice of utilizing approximately 15-30% of -4.76 mm oily mill scale fines containing ~0.4% oil and ~4.5% moisture in the sinter plant mix was stopped in late 1975. The oil on the mill scale volatilizes during sintering, the resulting non-condensable hydrocarbons increase the opacity of the stack gas, and the condensable hydrocarbons in the strand off-gas adversely affect the operation of the main stack baghouse because the pores in the filter bags are blinded by the entrapment of fine -0.044 mm oil-bearing baghouse dust which contains significant quantities of lime, alkali and iron oxide. Under these conditions, deoiling of the mill scale fines is required in order to sinter this material at relatively high concentrations in the sinter mix. For this reason, various mill scale deoiling technologies were evaluated, including water washing and thermal incineration methods. Mill scale fines are currently being deoiled by an outside contractor in a direct fired kiln for subsequent utilization in the sintering operation.

In this paper, existing deoiling technologies and the current processing of mill scale at Inland, including screening and deoiling, for consumption in the ironmaking and steelmaking operations are presented. The oily and deoiled mill scale are characterized on the basis of size, oil concentration, and chemical composition. Changes in the oxidation state of iron in the mill scale as a result of deoiling and the subsequent effect on the heat generated by exothermic oxidation of the mill scale during sintering are examined.

GENERATION AND CONSUMPTION OF MILL SCALE

The annual mill scale generation at Inland Steel has ranged from 3.7 to 4.7% of the annual raw steel production, which is similar to published mill scale generation rates.(1,2) In 1978, approximately 283,000 Mg of mill scale were generated, which amounted to 3.7% of the annual raw steel production. Mill scale is generated at the various slabbing, blooming, and rolling mill operations. The oil concentration on mill scale varies depending on the location of its generation (Table 1). The variation in the oil content and size of the mill scale necessitates blending prior to its consumption. Mill scale contains a high concentration of iron (72-75% Fe) and <4% gangue consisting of SiO_2, Al_2O_3, CaO and MgO (Table 2). The coarse sized mill scale is charged directly to the blast furnaces and the mill scale fines are sintered.

SCREENING OF MILL SCALE

Screening of freshly generated mill scale is done in order to produce three mill scale fractions for recycling in the ironmaking and steelmaking operations. As seen in Figure 1, the +150 mm mill scale contains mostly scrap and capping plates and is consumed in steelmaking (~0.5-2%), the -50+3.35 mm coarse mill scale is charged directly to the blast furnaces (~12-18%), and the -4.76 mm mill scale fines are utilized in sintering (~80-87%). Magnetic separation of the coarse -150+50 mm mill scale upgrades this material by discarding the non-magnetic refractory (~0.5%). Thus, it can be seen that mill scale fines comprised most of the mill scale generated in the steel plant.

It was found that moisture and oil adversely affect the screening of mill scale at finer sizes, such as 4.76 mm. The screening efficiency is improved as the moisture on the mill scale decreases. On the average, mill scale contains ~ 0.4% oil (range of 0.1-1.7%) and ~ 4.5% moisture (range of 1.4-10.2%). The oil and moisture concentrations decrease to some extent after blending and allowing the oil and moisture to drain by gravity (Table 1). This results in some improvement in the efficiency of screening mill scale. However, the -50+4.76 mm mill scale still contains 0.19% oil because of the presence of high oil bearing piggy-back fines (Tables 3 and 4). The removal of these fines from the surface of the coarse mill scale particles by drying the mill scale prior to screening improves the screening operation and produces an oversize scale with a lower oil content for direct blast furnace charging. This can be seen by comparing the oil content of the mill scale as received and after drying at 100°C for 24 hours (Table 4).

The oil concentration of mill scale is a function of the particle size. The oil and moisture contents increase with a decrease in particle size because of increased surface area, thereby resulting in increased surface absorption of the oil (Tables 1, 3, and 4).

DEOILING OF MILL SCALE FINES

The following methods were investigated for deoiling mill scale fines which were produced by screening mill scale at 4.76 mm:

1. Washing methods
2. Thermal incineration methods

The oil concentration of mill scale after deoiling should be as low as possible for utilization in the sinter plant equipped with a baghouse.

Washing Methods

Commercial deoiling of mill scale is done by water washing in a cyclone and a series of spiral rake classifiers at Stelco's (Steel Company of Canada's) Hilton Works, Hamilton, Ontario, and is operated by Uramco International.(3,4) Fine mill scale containing 3-6% oil is deoiled by this process to 0.2% oil. It is also claimed(4) that the oil content could be lowered further by the addition of oil breaking and emulsifying chemical compounds in the secondary screw classifiers. Approximately 10-15% of the mill scale generated at Stelco is deoiled by water washing and subsequently sintered together with mill scale fines which are relatively low in oil.

As noted in Table 5, the results of laboratory deoiling of -0.6 mm Inland mill scale fines by water washing with agitation indicate that as much as 60% and 70% of the oil was removed by using cold and hot water, respectively. In contrast, about 90% of the oil was removed by Colerapa Industries, Ravenna, Ohio, when the mill scale was deoiled on a laboratory scale in a 75 mm diameter cyclone by cold water washing. The mill scale in the cyclone underflow was recycled up to six times through the cyclone in a slurry form. No chemical additives were used in the test. Under these conditions, the mill scale was deoiled to a range of 0.06-0.18% oil which reflects the initial oil concentration.

The use of hot alkaline solution increased mill scale deoiling efficiency to 90% and achieved deoiling to 0.08% oil from an initial 2% oil concentration (Table 5). The use of hot alkaline water solution for deoiling fine high oil bearing mill scale sludge was demonstrated on a pilot plant scale in West Germany.(5)

Water washing deoils mill scale to ~0.1-0.2% oil. In order to deoil mill scale to lower oil levels, the solvent washing of mill scale by recyclable chlorinated hydrocarbons is currently being investigated by Colerapa Industries, Ravenna, Ohio. It is anticipated that an oil free mill scale product and oil will be obtained. The solvent washing process consists of oil extraction by a solvent, drying of the deoiled mill scale, and separation of oil and water from the solvent by distillation. In terms of oil recovery, this process may be more applicable to high oil bearing steel plant sludge materials containing 6-20% oil. With the increasing cost of fuel oil and natural gas used in various thermal deoiling methods, the solvent washing process(6) may become economically attractive; however, its technological viability remains to be proven.

Thermal Methods

Laboratory static (1.1 m^3/h air flow) and dynamic thermal deoiling tests indicate that mill scale is deoiled to $<0.01\%$ oil after 30 minutes at 315°C (Table 6 and Figure 2). The deoiling time could be reduced by increased temperature and, perhaps, gas flow rate.

The following pilot or plant scale thermal mill scale deoiling methods were investigated in which oil is volatilized from the surface of mill scale:

a) By utilizing the sensible heat of molten steelmaking slag,
b) By flash burning of oil from mill scale-lime mini-pellets,
c) In an external indirect-fired kiln, and
d) In an internal direct-fired kiln.

Molten Steelmaking Slag

In this method, the sensible heat of molten steelmaking slag, a waste heat source in the steel plant, is utilized to deoil mill scale fines by contact in a slag pit. Successive layers of oily mill scale fines and molten slag result in the devolatilization and ignition of oil on the mill scale.(7)

Approximately 200 Mg of -4.76 mm mill scale fines containing ~0.3% oil was deoiled by about 400 Mg of No. 4 BOF steelmaking slag. The slag temperature was 1437°C. On contact, oil from a 100-150 mm thick layer of mill scale is partially devolatized and subsequently forms a big fire ball. The remaining oil continues to burn in the form of small flames (less than 250 mm high) at several broken slag/air interfaces. At these interfaces, bluish grey hydrocarbon fumes were noticed when the slag-mill scale mixture was water quenched, which indicates that hydrocarbon emissions are a problem with this process.

After cooling, the mill scale particles beneath the slag layer retained their size structure and did not appear to dissolve in the slag matrix. This observation indicates the possibility of concentrating the deoiled mill scale fines in the screen undersize by screening the slag-scale mixture at 6.35 mm. The separation of the mill scale fines from the screened slag-scale mixture by magnetic separation was not satisfactory because mill scale contains significant quantities of antiferromagnetic wustite and hematite, besides ferromagnetic magnetite and metallic Fe.

The mill scale was deoiled to <0.07% oil. The aforementioned hydrocarbon emission problem coupled with excessive fine dust generation during the handling and processing of the scale-slag mixture precludes the deoiling of mill scale by this method, unless the process is modified in order to render it environmentally acceptable.

Flash Burning of Mill Scale-Lime Mini-Pellets

Deoiling of mill scale fines by the Inland flash burning process(8) involves the following:

1. Mixing and balling of ~90% by weight of -4.76 mm mill scale fines with ~10% by weight of -3.35 mm burnt lime fines at ~8% moisture to produce mini-pellets.
2. Air drying the mill scale-lime mini-pellets to less than 6% moisture for better strength, less spalling and ease in handling prior to deoiling.

3. Deoiling of the partially dried mini-pellets on a pan conveyor by an impinging burner flame at a pellet surface temperature of about 315°C.

Deoiling by flash burning is the result of ignition of oil at the pellet surface; the oil appears to concentrate on the surface of the mini-pellet due to capillary action associated with the burnt lime. It was found that the heat source for flash burning should have a flame temperature of at least 650°C for complete combustion of the hydrocarbons in the waste gas. In a pilot test run, natural gas burners were used which yielded a flame temperature of about 1000°C. A 25-40 mm thick layer of the mini-pellets was deoiled by a vertical impingement of the flame. The retention time for flash burning was about 1.5 minutes when the pan conveyor speed was 1.8 m/min. The natural gas consumption and the throughput rate were a function of the moisture content of the air dried mini-pellets. Specifically, as the air-dried mini-pellet moisture varied from 2.9 to 5.2%, the energy consumption and throughput rate changed from 663 to 882 kJ/kg and 7.2 to 4.9 Mg/h, respectively. Under these conditions, the oil content was reduced from 0.42% to 0.07%.

Indirect-Fired Kiln

In a pilot scale test run, about 180 Mg of -4.76 mm mill scale fines were deoiled in an unlined indirect fired kiln utilizing natural gas as a fuel. The kiln residence time was estimated to be about 23 minutes and the shell temperature was 427°C. The initial and deoiled products averaged 0.58 and 0.08% oil, respectively.

Deoiling mill scale in an indirect-fired kiln was done in an attempt to recover oil by collecting condensable hydrocarbons for reuse. The recovered oil from mill scale could lower the fuel consumption, and its quantity would reflect the initial oil concentration and oil recovery efficiency. The hydrocarbon recovery system consisted of a primary condensor, a spray washer and a skimmer tank. A centrifugal blower with a capacity of 0.472 Nm^3/s was used to inject the kiln off-gas into the hydrocarbon recovery units.

The hydrocarbons produced by mill scale deoiling consisted of two components: a light oil and a heavy greasy sludge. The light oil can be readily recovered; however, the recovery of the heavy oil from the greasy sludge requires a distillation step. No quantitative data was obtained regarding the recovery of the oils. A detailed evaluation of the properties of the oils will be needed to develop a hydrocarbon recovery flow sheet.

In the pilot scale test, inadequate condensation resulted in excessive generation of a white mist in the final exhaust gas. The mist may contain uncondensed and non-condensable hydrocarbons; if this is the case, an environmental control device may be needed to combust the hydrocarbons prior to discharging the kiln off-gas in the atmosphere. Another alternative is to recycle the mist-bearing gas to the combustion unit used for generating the external kiln heating gas. In addition, the possibility of eliminating or minimizing mist generation in the kiln off-gas should be investigated by changing the kiln operating conditions such as the oxygen potential, residence time, and temperature.

Direct-Fired Kiln

Pilot scale deoiling tests were conducted in a direct-fired kiln at Miller Compressing Company, Milwaukee, and Walker Corporation, Gary, respectively. The results showed that it is possible to consistently produce a deoiled mill scale product analyzing <0.01% oil. In the Miller kiln (1.4 m diameter x 6.1 m long), approximately 40 Mg of -4.76 mm Inland mill scale fines containing 1.0% oil was deoiled at a throughput rate of 5-6 Mg/h. In the Walker kiln (3 m diameter x 20 m long), -4.76 mm Inland mill scale fines containing 0.5% oil were deoiled at a throughput rate of 25 Mg/h. The kiln off-gas temperature for both kilns was in the range of 500°C. The hydrocarbons in the kiln off-gas were combusted by after-burners prior to final discharge from the stack.

On the basis of the consistent low concentration of oil obtained from a direct-fired kiln, it was decided that Inland mill scale should be deoiled on a commercial basis in a direct-fired, refractory lined kiln. Therefore, since October, 1978, about 27,300 Mg/month oily mill scale fines have been deoiled by this method for utilization in the sintering operation.

The direct-fired kiln used for deoiling mill scale is a counter-current reactor in which air is drawn from the mill scale exit end. The kiln (3 m diameter x 20 m long) operates at 7 rpm and uses an average of 23.6 dm^3/Mg of No. 2 fuel oil to deoil the mill scale in the kiln and to combust off-gas hydrocarbons in after-burners (Table 7). It was found necessary to maintain a minimum kiln off-gas temperature of ~315°C in order to deoil mill scale to <0.01% oil. For complete combustion of the hydrocarbons, the two after-burners have to be operated at 650°C; approximately 40% of the total fuel oil consumed is utilized in the after-burners. The kiln off-gas is cleaned of fine solid particulates by a wet scrubber prior to discharge to the atmosphere. The deoiled wet scrubber sludge is added to the deoiled kiln product in minor quantities and then sintered. The breech material, which is collected by gravity from the kiln off-gas at the kiln feed end, is recycled (Figure 3).

Comparison of Various Mill Scale Deoiling Methods

Water washing resulted in the deoiling of mill scale fines to 0.06-0.18% oil depending upon the initial oil concentration (0.3-2.0%). Organic solvent washing may achieve deoiling to a lower level, however, this remains to be proven.

Of the thermal mill scale deoiling methods investigated, the direct-fired kiln gave the best result by consistently producing a deoiled mill scale product containing $<$0.01% oil (Table 7). The other thermal deoiling methods deoiled mill scale to about 0.08% oil, and the fuel consumption would increase if deoiling to lower levels is required. The direct-fired kiln deoiling of mill scale uses about 40% of the total fuel in combusting hydrocarbons in the waste gas, which may also be needed in an external indirect-fired kiln to the extent that the remaining uncondensed and non-condensable hydrocarbons in the waste gas from the hydrocarbon recovery system cause environmental problems.

The fuel consumption in the thermal deoiling methods, as given in Table 7, cannot be compared realistically because of the variability in the oil concentration of the final deoiled product, the presence and absence of pollution control devices to combust hydrocarbons in the waste gas, and the sizes of the plants. Furthermore, in the case of indirect-kiln deoiling, the kiln was not lined with refractory and the recovery of hydrocarbons could not be quantitatively established.

The cost of fuel oil makes the thermal deoiling of mill scale very expensive. Less energy intensive mill scale deoiling processes, which include washing by water(3) and/or organic solvents(6), and flash-burning(7,8) may become attractive. In some of the thermal deoiling methods, environmental control devices may be needed to control hydrocarbon emissions. In addition, process changes may, in some instances, be required to obtain a deoiled mill scale product with a lower oil content.

UTILIZATION OF MILL SCALE

It was stated earlier that the screening of mill scale is necessary for recycling in ironmaking and steelmaking operations. At Inland Steel, the +50 mm mill scale contains mostly capping plates and scrap and is recycled in steelmaking operations (Figure 1). The -50+3.35 mm coarse low oil-bearing mill scale is recycled through the blast furnace as a direct metallic charge. The -4.76 mm mill scale fines are sintered, but must be deoiled in order to be used at high concentrations in the mix. In this section, the utilization of mill scale fines in sintering is discussed - at low concentrations of oily mill scale fines and high concentrations of deoiled mill scale fines. In addition, both oily and deoiled mill scale fines are characterized with respect to iron oxidation state and mineralogy, followed by thermodynamic calculations regarding the exothermic oxidation of mill scale during sintering.

Based on the sinter plant experience, it is possible at Inland to recycle oily mill scale fines up to a concentration of 7% of the raw sinter mix (or 5% of the sinter burden, which includes the return fines and coke breeze) without causing baghouse and other operational problems.

The deoiling of mill scale is required in order to utilize mill scale at concentration greater than 7% in the sinter plant. Therefore, since September, 1978, about 240,000 Mg of deoiled mill scale fines were produced in a direct-fired kiln. The entire deoiled mill scale product was sintered in concentrations ranging from 20-30% of the raw sinter mix.

Mill scale contains exothermic iron and iron oxide constitutents which affect the heat balance of the sintering operation. Therefore, the sinter mix composition becomes important in maintaining proper heat input to the mix by the usage of endothermic sinter flux stone and by control of exothermic carbon- and iron-bearing materials, such as blast furnace flue dust, steelmaking slag which contains metallic iron, and mill scale. In this regard, the oxidation states of the iron were determined for oily and direct-fired kiln deoiled mill scale fines. Based on this data, calculations of the heat generated during mill scale oxidation were made for a sintering temperature of 1327°C.

As noted in Table 8, the metallic iron concentration varied from 3.0 to 10.8% for three samples of oily mill scale fines produced by screening at 16, 12.5, and 4.76 mm, which may be the result of sample inhomogeneity, inaccurate chemical analysis, or variability in the oxidation states of iron in mill scale due to the varying processing conditions employed at the various mill operations. The total Fe, Fe^{++}, and Fe^{+++} concentrations in the mill scale did not change significantly during the deoiling operation. However, in the case of the direct-fired kiln wet scrubber sludge (Figure 3), the Fe^{++}

and metallic Fe concentrations were relatively low and the Fe^{+++} content was relatively high because the particles in the scrubber sludge are finer and subjected to higher temperatures in order to combust hydrocarbons in the kiln off-gas.

On the basis of the concentrations of the various iron forms, and assuming that one percent of the magnetic Fe, as determined by Satmagan, is equivalent to 2.49% metallic Fe(9,10) and that the antiferromagnetic wustite and hematite do not contribute towards the magnetic susceptibility measurement by the Satmagan unit,(10) the iron mineralogy of the oily and deoiled mill scale fines was determined. The data presented in Table 9 shows that, as a result of deoiling, the magnetite and metallic Fe concentrations increased while the wustite and hematite concentrations decreased.

The heat generated by the oxidation of wustite, magnetite, and metallic Fe to hematite at a sintering temperature of 1327°C is presented in Table 10. On a constant mass basis, metallic Fe and wustite generate respectively about 14.4 and 3.9 times more heat than magnetite. Therefore, any change in the initial metallic iron concentration of mill scale would have a significant effect on the heating value of mill scale. Comparing the respective iron mineralogy and heat generation data given in Tables 9 and 11, the heating value of mill scale appears to be more sensitive to the initial metallic Fe content than to changes in the iron mineralogy due to deoiling. A metallic Fe concentration change from 3 to 5.6% and 10.8% resulted in a respective 24% and 42% increase in the total heat generated by mill scale (Table 11). However, only up to 10% excess heat can be generated by changes in the oxidation states of iron in mill scale as a result of deoiling. The wet scrubber sludge from the direct-fired kiln deoiling operation is oxidized due to the high temperature combustion of hydrocarbons at 650°C, and, as a result, contains less oxidative heat than mill scale.

The excess heat of deoiled mill scale may be compensated to some extent by the combustion of oil on oily mill scale which is a function of the type of oil, initial oil concentration and degree of volatilization and combustion during a single or multiple pass(es) of air or strand off-gas (waste gas) through the sinter bed.(11) Calculations show that 0.3 to 0.4% oil on mill scale will generate 0.13×10^{-6} to 0.17×10^{-6} kJ/Mg of heat on complete combustion. This amounts to about 7 to 13% of the heat generated from the oxidation of oily mill scale (Table 11). The combustion of oil on mill scale occurs to a limited extent without waste gas recirculation through the sinter bed. In view of the above, more heat may be generated by the deoiled mill scale fines when compared with the oily mill scale fines while sintering a mix containing identical mill scale concentrations.

The effect of mill scale deoiling on the permeability of the sinter mix containing deoiled mill scale could be another potential problem affecting sinter production. The size distributions of the oily and deoiled mill scale fines, as well as that of the wet scrubber sludge, are presented in Table 12. About 4% more of the -0.15 mm fines was generated in the kiln. The deoiled kiln product mixed with minor amounts of the wet scrubber sludge is sintered; the mix contains 21.5% -0.15 mm fines, as opposed to 8.7% -0.15 mm fines in the case of the oily mill scale fines. An increase in the concentration of -0.15 mm fines in the mill scale decreases the mix permeability. Furthermore, the wetting characteristics of the deoiled mill scale by water will be different than that of the oily mill scale because of the hydrophobic nature of the oily mill scale. The mix permeability may be increased by balling the sinter mix containing mill scale prior to sintering because of an increase in the apparent mean size of the mix and a subsequent decrease in the effective concentration of the -0.15 mm fines contained in the mix. Balling of the deoiled mill scale fines may have a beneficial effect on the sinter mix permeability and sinter plant productivity.

The sinter bed permeability can be improved by reducing the bed height for a specific suction level. The downward movement of the flame front during sintering coupled with the flow of preheated air and waste gas increases the maximum bed temperature as the height increases, especially in the lower bed region near the grate. Under these conditions, the heat generated by mill scale oxidation in the bed could cause slagging of the bed, particularly in the lower bed region, because of relatively higher bed temperatures. This effect can be seen from Table 13, where reduction in bed height at an increased mill scale concentration of 30% resulted in the attainment of generally similar bed permeability, as evidenced by a similar value of suction in the last windbox (No. 21), as when 22% deoiled mill scale was used in the sinter plant. However, the sinter plant productivity dropped. This may be partially due to increased cold return fines generation, which reflects lower sinter quality, as well as lower sintering temperatures, as evidenced by a lower strand off-gas temperature. The adverse effects of deoiled mill scale on sinter bed permeability, productivity, and sinter quality can probably be reduced by proper sinter mix preparation and process conditions.

SUMMARY

Utilization of mill scale in sintering requires screening of mill scale. In the case of a sinter plant equipped with a baghouse, deoiling of mill scale fines in necessary. Therefore, various mill scale deoiling methods were investigated. The water washing of mill scale removes up to 90% of the oil, provided a hot alkaline solution with stirring or intense agitation with a high volume of water in a unit such as a cyclone is used. The deoiling of mill scale by thermal methods was investigated by utilizing the sensible heat of molten steelmaking slag, by flash burning of oil on mill scale-lime mini-pellets by a burner flame on a pan conveyor, and in a direct- or indirect-fired kiln. The direct-fired kiln consistently gave the best deoiled product, which analyzed <0.01% oil. Hence, the Inland mill scale fines are currently deoiled in a direct-fired kiln. All of the deoiled mill scale fines are utilized in the sinter plant in concentrations of 20 to 30% of the raw sinter mix.

Both the oily and deoiled mill scale fines were characterized with respect to size, chemistry, magnetic iron content and iron mineralogy. Mill scale is high in iron and low in impurities, making it a prime material for recycling. The oil concentration increased with decreased particle size of oily mill scale. Calculations of the heating value of mill scale resulting from the oxidation at 1327°C of iron and iron oxides in the mill scale indicated that direct-fired kiln deoiling increased the heating value.

The high cost of fuel oil makes thermal direct-fired kiln deoiling of mill scale rather expensive, especially when about 40% of the total fuel consumed is needed for environmental control. Under these conditions, other mill scale deoiling methods, such as the use of organic solvents for washing, or low energy thermal methods, may become attractive.

REFERENCES

1. Pastzov, L., and Floyd, S. B., "Managing and Disposing of Residues from Environmental Control Facilities in the Steel Industry," Dravo Research, EPA Contract No. HR-803619, June, 1976, p. 118.

2. Recycling of Steel Plant Waste Materials, British Steel Corporation, Steelresearch 74, 1974, p. 19.

3. "Steel Industry Sludge is Being Reused," Environmental Science and Technology, Vol. 9, July, 1975, p. 624, and "Recycling Mill Sludge-Profitably," Industry Week, Vol. 181, No. 11, June 10, 1974, p. 44.

4. Duval, L. A., "Method and Apparatus for Processing Waste Water Slimes of Steel Mill Water Treatment Systems," U. S. Patent No. 3,844,943, October 4, 1974.

5. Supp, A., and Zimmermann, K., "Untersuchungen Zn Entolung Von Walzzunder, Techn. mIH. Krupp. Forsch. Bar, Vol. 33, 1975, #3, p. 89; ibid, Stahl U Eisen, Vol. 96, November, 1976, No. 23, p. 1177.

6. Bahrke, L., Method for Degreasing Roll Mill Scale," German Patent No. 2532689, July 25, 1975.

7. Pack, P. R., "Method for Removing Oil from Mill Scale and Recovering Metallic Values Therein," U. S. Patent Application No. 908894 Filed on May 23, 1978, U.S. Patent document No. 4,177,062, dated December 4, 1979, assigned to Harsco Corporation.

8. Schwarz, A. M., "Method of Deoiling and Agglomerating Mill Scale," U. S. Patent Application No. 06/056,331 Filed on July 10, 1979.

9. Gaudin, A. M., "Principles of Mineral Dressing," McGraw-Hill, 1939, p. 436.

10. Cullity, B. D., "Introduction to Magnetic Materials," Addison-Wesley, 1972, pp. 12, 157, 190.

11. Ban, T. E., "Ore-Sintering Process Reduces Air Pollutants," Process Technology, Chemical Engineering, Vol. 85, No. 14, June 19, 1978, p. 81.

SRB/jrb

TABLE 1

Oil and Moisture Concentration of Mill Scale

Mills	Oil, %	Moisture, %	-3.35 mm, %
80" Hot Strip Mill			
No. 1 Pit	0.43	7.4	85
No. 2 Pit	2.00	11.0	100
No. 4 Slabber Mill			
North Pit	0.26	2.1	32
South Pit	0.59	10.2	96
No. 3 Blooming Mill	0.21	1.4	67
No. 2 Blooming Mill	0.16	1.5	37
28" Structural Mill	0.10	2.5	37
14" Bar Mill	0.30	3.2	87
12" Bar Mill	0.70	6.4	89
10" Bar Mill	1.10	5.6	93
Mill Scale Fines			
-12.5 mm Freshly Generated	0.38	4.4	80
-4.76 mm Stored Pile*	0.27	4.0	88
Raw Mill Scale	~ 0.40	~ 4.3	~ 70

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* For at least a six-month period.

TABLE 2

Chemistry of -4.76 mm Oily Mill Scale Fines

	Weight % (Dry Basis)
Total Fe	72-75
Fe^{++}	45-50
Fe^{+++}	19-23
Metallic Fe	3-11
Magnetic Fe	26-28
Gangue*	< 4
Oil	~ 0.4

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* Includes SiO_2, Al_2O_3, CaO, MgO

TABLE 3

Oil Concentration of Stored Mill Scale

Mill Scale	wt., %	oil, %	Oil Units	Oil Distribution, %
Coarse (85% -50+4.76 mm)	18.4	0.19	0.035	12.2
Fines (96% -4.76 mm)	81.6	0.31	0.253	87.8
Total	100.0	ND	0.288	100.0

Mill Scaled Fines (96% -4.76 mm) Air Dried to 0.6% Moisture*

Screen Size (mm)	wt., %	oil, %	Oil Units	Oil Distribution, %
+3.35	12.3	0.16	0.027	6.1
-3.35 +2.00	14.8	0.21	0.031	9.5
-2.00 +1.00	13.9	0.28	0.039	11.9
-1.00 +0.50	23.1	0.30	0.069	21.1
-0.50 +0.25	13.0	0.35	0.046	14.1
-0.25 +0.15	11.1	0.45	0.050	15.3
-0.15	11.8	0.61	0.072	22.0
Total	100.0	0.32	0.327	100.0

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* In order to facilitate screening at finer sizes.

ND: Not Determined

TABLE 4

Oil Concentration of Stored -4.76 mm Mill Scale Fines as a Function of Moisture

	As-Received		Oven Dried (100°C, 24 h)	
Moisture, %	3.2		0	
Oil, %	0.35		0.26	
Screen Size (mm)	wt., %	oil, %	wt., %	oil, %
+6.35	2.0	0.15	1.6	0.06
-6.35 +4.76	4.3	0.13	3.6	0.10
-4.76 +3.35	8.9	0.16	7.5	0.12
-3.35 +2.00	18.3	0.24	15.5	0.17
-2.00 +1.00	24.2	0.26	17.2	0.19
-1.00	42.3	0.55	54.6	0.41
Total	100.0	0.36	100.0	0.36

TABLE 5

Water Washing of Inland Mill Scale

	Oil on Mill Scale, %		Oil	Time,	
	As-Received	After Washing	Removed, %	min.	Washing Condition
Test Done by Inland					
80" Hot Strip Mill, No. 2 Pit (-0.60 mm)	2.00	1.00	50		Cold water at 25°C, stirred
	2.00	0.90	55		
	2.00	0.80	60	10	
	2.00	1.00	50		Hot water at 80°C, stirred
	2.00	0.90	55		
	2.00	0.70	65		
	2.00	0.60	70	10	
	2.00	0.46	77	5	Hot alkaline solution (PARCO 338) at 80°C, stirred
	2.00	0.08	97	10	
Test Done by Colerapa Industries					
14" Bar Mill (-3.35 mm)	0.32	0.09	72	-	Cold water washing in a 75 mm diameter cyclone
No. 4 Slabber, North Pit (-16.00 mm)	0.24	0.06	69	-	
No. 4 Slabber, South Pit (-0.60 mm)	0.59	0.12	80	-	
80" Hot Strip Mill, No. 1 Pit (-3.35 mm)	0.43	0.09	79	-	
80" Hot Strip Mill, No. 2 Pit (-0.60 mm)	1.81	0.18	90	-	

TABLE 6

Laboratory Thermal Deoiling of Mill Scale

	Deoiling Conditions		Oil, %	
	Mill Scale Temperature, °C	Time, min.	As-Received	Deoiled Product
Static Deoiling in a Muffle Furnace				
Screened Mill Scale Fines (-4.76 mm)	315	30	0.6	< 0.01
No. 3 Bloomer Mill (-12.5 mm)	315	30	0.3	< 0.01
No. 4 Slabber Mill (-6 mm)	315	30	0.6	< 0.01
80" Hot Strip Mill, #2 Pit (-0.6 mm)	315	30	2.0	< 0.01
Dynamic Deoiling in a 0.48 m Diameter x 0.61 m kiln rotating at 10 rpm				
Screened Mill Scale Fines (-4.76 mm)	~315	~30	1.3	< 0.01

TABLE 7

Comparison of Various Thermal Mill Scale Deoiling Methods

	Commercial Direct-Fired Kiln	Pilot Scale Indirect-Fired Kiln	Pilot Scale Flash Burning on Pan Conveyor
Material	-4.76 mm mill scale fines, 4% moisture	-4.76 mm mill scale fines, 2.5% moisture	Mini-pellets containing ~90% -4.76 mm mill scale fines, and ~10% -3.18 mm burnt lime fines and ~8% moisture, as produced, and 2.9-5.2% moisture, after air drying
Unit Size	3 m diameter x 20 m long kiln	1.5 m diameter x 6.1 m long kiln	1.5 m wide x 4.9 m long pan conveyor
Feed Rate, Mg/h	55	8.8	7.2
Deoiling Temperature, °C	N.D.	427*	315
Exhaust Gas Temperature, °C	315-330	N.D.	315-330
Volume, Nm^3/Mg	700	190	250
Fuel Used for Deoiling	No. 2 Fuel Oil	Natural Gas	Natural Gas
Fuel Consumption, kJ/kg	942**	1030	663-882***
Mill Scale Oil Content, %			
Initial	0.40	0.58	0.42
Final	<0.01	0.08	0.07

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* Kiln shell temperature of 427°C.

** Includes fuel oil consumed for combusting hydrocarbons in the kiln off-gas.

*** Fuel consumption varied as a function of mini-pellets moisture.

ND: Not Determined

TABLE 8

Analysis of Oily and Deoiled Mill Scale Fines

	-16 mm Mill Scale			-12.5 mm Mill Scale		-4.76 mm Mill Scale	
	Oily*	Deoiled*	Wet Scrubber Sludge	Oily	Deoiled	Oily**	Deoiled**
Total Fe (%)	72.5	72.9	70.3	74.9	74.6	75.3	76.2
Fe++	46.3	45.3	35.4	50.6	49.1	45.0	45.9
Fe+++	23.2	24.3	34.3	18.7	17.0	19.5	18.7
Metallic Fe	3.0	3.3	0.6	5.6	8.5	5.6 5.2*** 10.8	5.4 6.2*** 11.6
#Magnetic Fe	26.4	37.5	35.6	28.0	38.0	26.6	35.3
+Oil, %	0.60	<0.01	<0.01	0.44	<0.01	0.34	<0.01
+Moisture, %	3.70	0.02	7.60	3.70	0.00	3.70	0.00

The various Fe analyses were made on the following ground mill scale samples:

* -0.18 mm ground fraction (~85% by weight of total sample)

** -0.21 mm ground fraction except for total Fe which was based on the weighted average of +0.21 mm and -0.21 mm ground fractions, and for metallic Fe, marked***, the +0.21 mm ground fraction was used.

The various Fe analyses for -12.5 mm mill scale were based on the weighted average of +0.21 mm and -0.21 mm ground fractions.

+ The oil and moisture were analyzed on the unground mill scale sample.

The magnetic iron is determined by Satmagan, which is calibrated to measure the magnetic susceptibility for magnetite.

TABLE 9

Calculated Iron Mineralogy of Oily and Deoiled Mill Scale Fines

	-16 mm Mill Scale			-12.5 mm Mill Scale		-4.76 mm Mill Scale	
Iron Mineralogy, %	Oily	Deoiled	Wet Scrubber Sludge	Oily	Deoiled	Oily	Deoiled
Wustite (FeO)	51.6	45.8	31.0	59.2	56.1	52.6	49.8
Magnetite ($FeO \cdot Fe_2O_3$)	26.2	40.5	47.1	19.4	23.2	17.6	30.1
Hematite (Fe_2O_3)	15.2	6.4	16.6	13.3	8.3	15.7	6.0
Metallic Iron (Fe)	3.0	3.3	0.6	5.6	8.5	10.8	11.6

The iron mineralogy was calculated on the basis of the chemical and magnetic iron analyses as given in Table 8.

TABLE 10

Heat Generated During Oxidation to Hematite (Fe_2O_3) at 1327°C

Iron Mineralogy	ΔH, kJ/Mg x 10^{-6}	Heat Generated Relative to Magnetite
Magnetite ($FeO \cdot Fe_2O_3$)	-0.498	1.000
Wustite (FeO)	-1.926	3.867
Metallic Iron (Fe)	-7.163	14.384

TABLE 11

Heat Generated by the Oxidation to Hematite of Oily and Deoiled Mill Scale Fines at 1327°C

	-16 mm Mill Scale			-12.5 mm Mill Scale		-4.76 mm Mill Scale	
	Oily	Deoiled	Sludge*	Oily	Deoiled	Oily	Deoiled
ΔH, kJ/Mg x 10^{-6}	-1.320	-1.340	-0.880	-1.638	-1.805	-1.874	-1.940
Relative to Oily Mill Scale	1.000	1.015	0.667	1.000	1.102	1.000	1.035

	Oily Mill Scale			Deoiled Mill Scale		
	-16 mm	-12.5 mm	-4.76 mm	-16 mm	-12.5 mm	-4.76 mm
Metallic Fe, %	3.0	5.6	10.8	3.3	8.5	11.6
ΔH, kJ/Mg x 10^{-6}	-1.320	-1.638	-1.874	-1.340	-1.805	-1.940
Relative	1.000	1.241	1.420	1.000	1.347	1.448

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* From the wet scrubber.

TABLE 12

Screen Analysis of -4.76 mm Oily and Deoiled Mill Scale Fines

Screen Size (mm)	Oily Mill Scale		Deoiled Mill Scale					
	Feed to Kiln		Kiln Product		Kiln Product + Wet Scrubber Sludge*		Wet Scrubber Sludge	
	wt. %	Cum. wt. %	wt. %	Cum. wt. %	wt. %	Cum. wt. %	wt. %	Cum. wt. %
+6.35	1.6	1.6	0.4	0.4	0.6	0.6	0.0	0.0
-6.35 +4.76	3.6	5.2	1.0	1.4	1.8	2.4	0.2	0.2
-4.76 +3.35	7.5	12.7	3.0	4.4	3.3	5.7	0.1	0.3
-3.35 +2.00	15.5	28.2	8.8	13.2	8.1	13.8	0.2	0.5
-2.00 +2.00	17.2	45.4	13.5	26.7	16.4	30.2	0.2	0.7
-1.00 +0.50	22.3	67.7	28.4	55.1	24.7	54.9	0.2	0.9
-0.50 +0.25	13.2	80.9	18.8	73.9	13.3	68.2	5.3	6.2
-0.25 +0.15	10.4	91.3	13.8	87.7	11.3	79.5	15.8	22.0
-0.15	8.7	100	12.3	100	21.5	100	78.0	100
Moisture, %	3.2		0.00		3.2		7.6	
Oil, %	0.35		0.01		0.01		0.01	

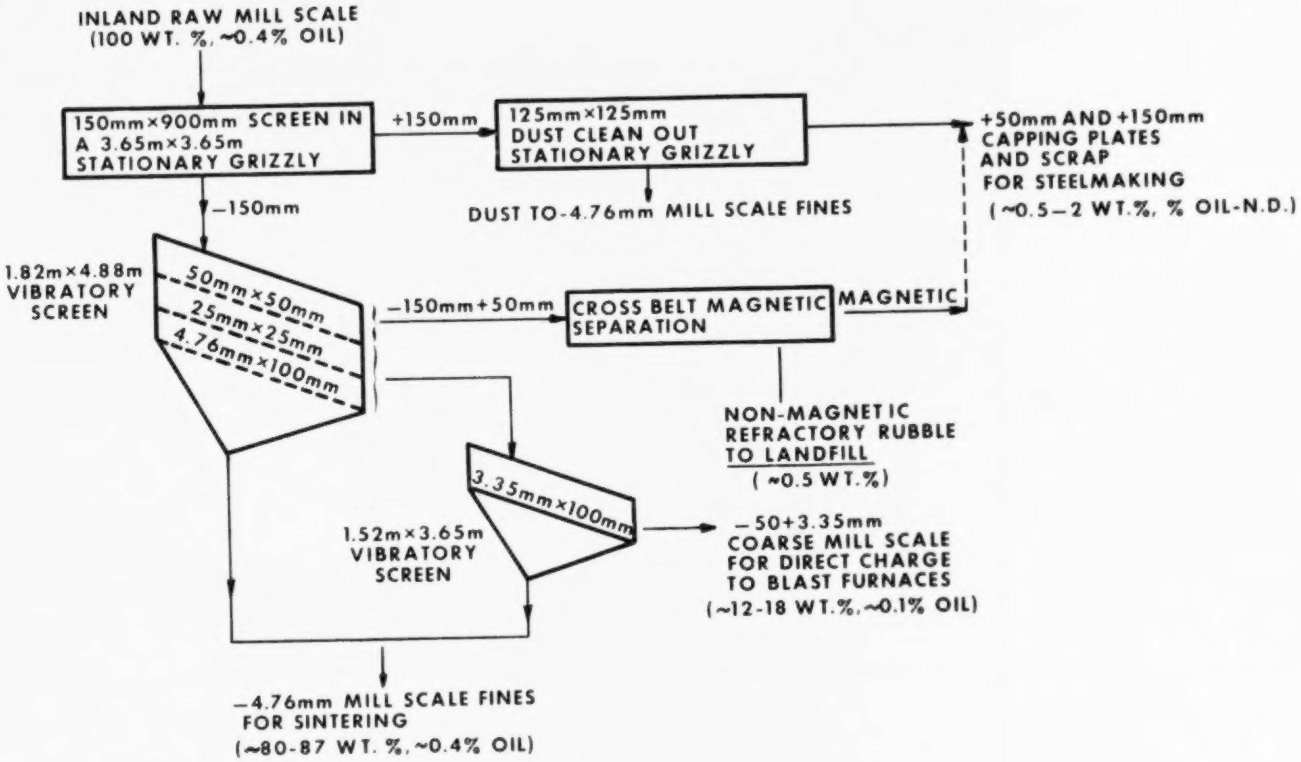
---

* Used in the sinter plant.

TABLE 13

Sinter Plant Operating Data for Mixes as a Function of Deoiled Mill Scale Concentration

	Deoiled Mill Scale in the Mix	
	22%	30%
Process Variables		
Bed Height, mm	434	394
Last windbox (No. 21) suction, kPa	4.7	5.2
Last Windbox (No. 21) Off-Gas Temperature, °C	147	114
Cold Return Fines (-6.35 mm), %	19.7	24.3
Sinter Quality		
Bases (CaO + MgO), %	24.3	22.2
Basicity (CaO + MgO)/(Al_2O_3 + SiO_2)	3.3	3.1
Strength Index-Impact, +3.35 mm, %	72.0	71.5
Sinter Strand Availability, %	87.2	85.2
Sinter Production, Mg/m^2/d		
Actual	25.3	23.1
Normalized to 100% Sinter Strand Availability	28.9	26.9


INLAND RAW MILL SCALE
(100 WT. %, ~0.4% OIL)
150mm×900mm SCREEN IN A 3.65m×3.65m STATIONARY GRIZZLY
+150mm
125mm×125mm DUST CLEAN OUT STATIONARY GRIZZLY
+50mm AND +150mm CAPPING PLATES AND SCRAP FOR STEELMAKING
(~0.5–2 WT.%, % OIL-N.D.)
−150mm
DUST TO-4.76mm MILL SCALE FINES
1.82m×4.88m VIBRATORY SCREEN
50mm×50mm
25mm×25mm
4.76mm×100mm
−150mm+50mm
CROSS BELT MAGNETIC SEPARATION
MAGNETIC
NON-MAGNETIC REFRACTORY RUBBLE TO LANDFILL
(~0.5 WT.%)
3.35mm×100mm
1.52m×3.65m VIBRATORY SCREEN
−50+3.35mm COARSE MILL SCALE FOR DIRECT CHARGE TO BLAST FURNACES
(~12-18 WT.%, ~0.1% OIL)
−4.76mm MILL SCALE FINES FOR SINTERING
(~80-87 WT. %, ~0.4% OIL)

N.D.: NOT DETERMINED

FIGURE 1 SCHEMATIC DIAGRAM OF THE SCREENING OF INLAND MILL SCALE

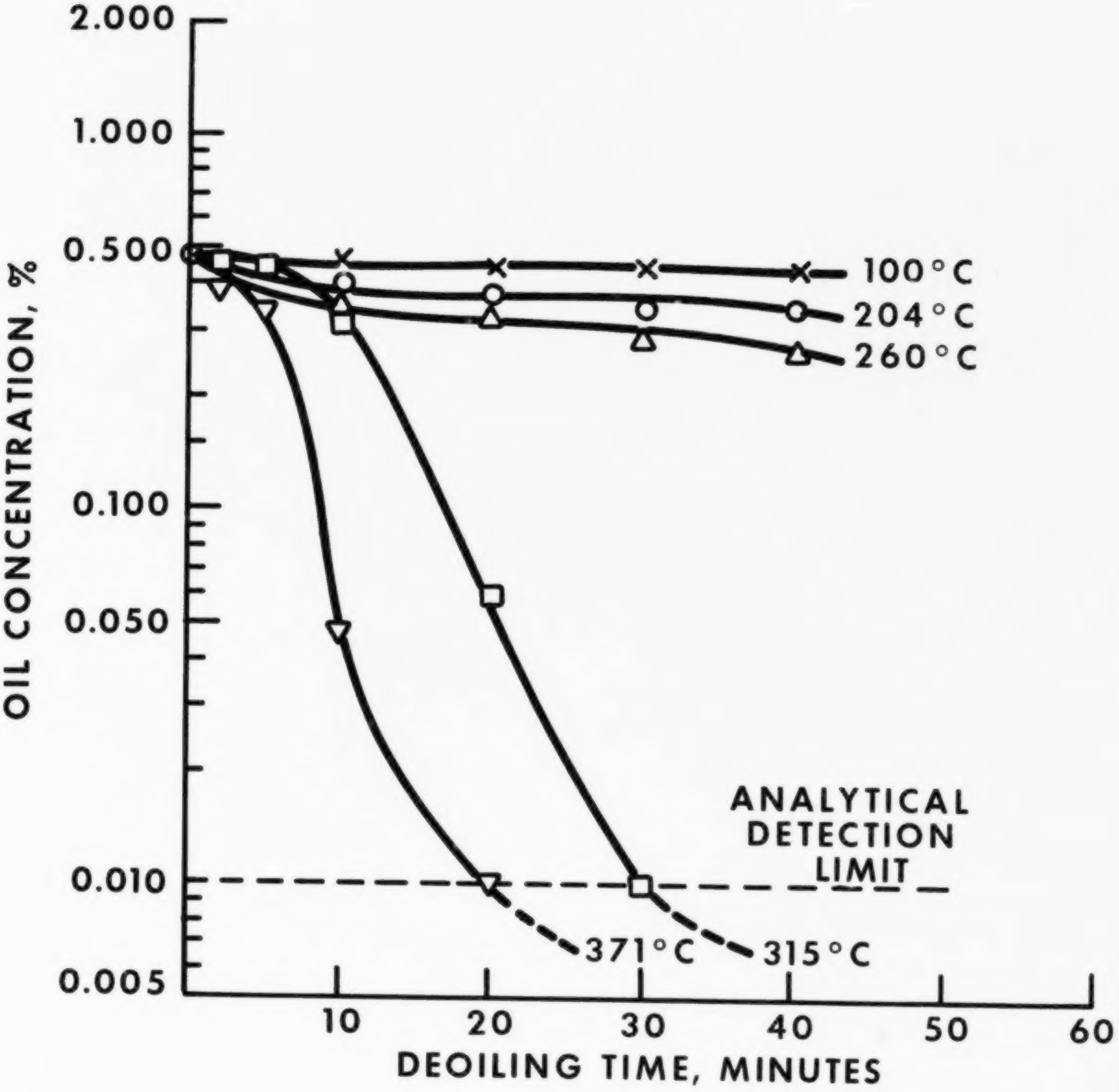
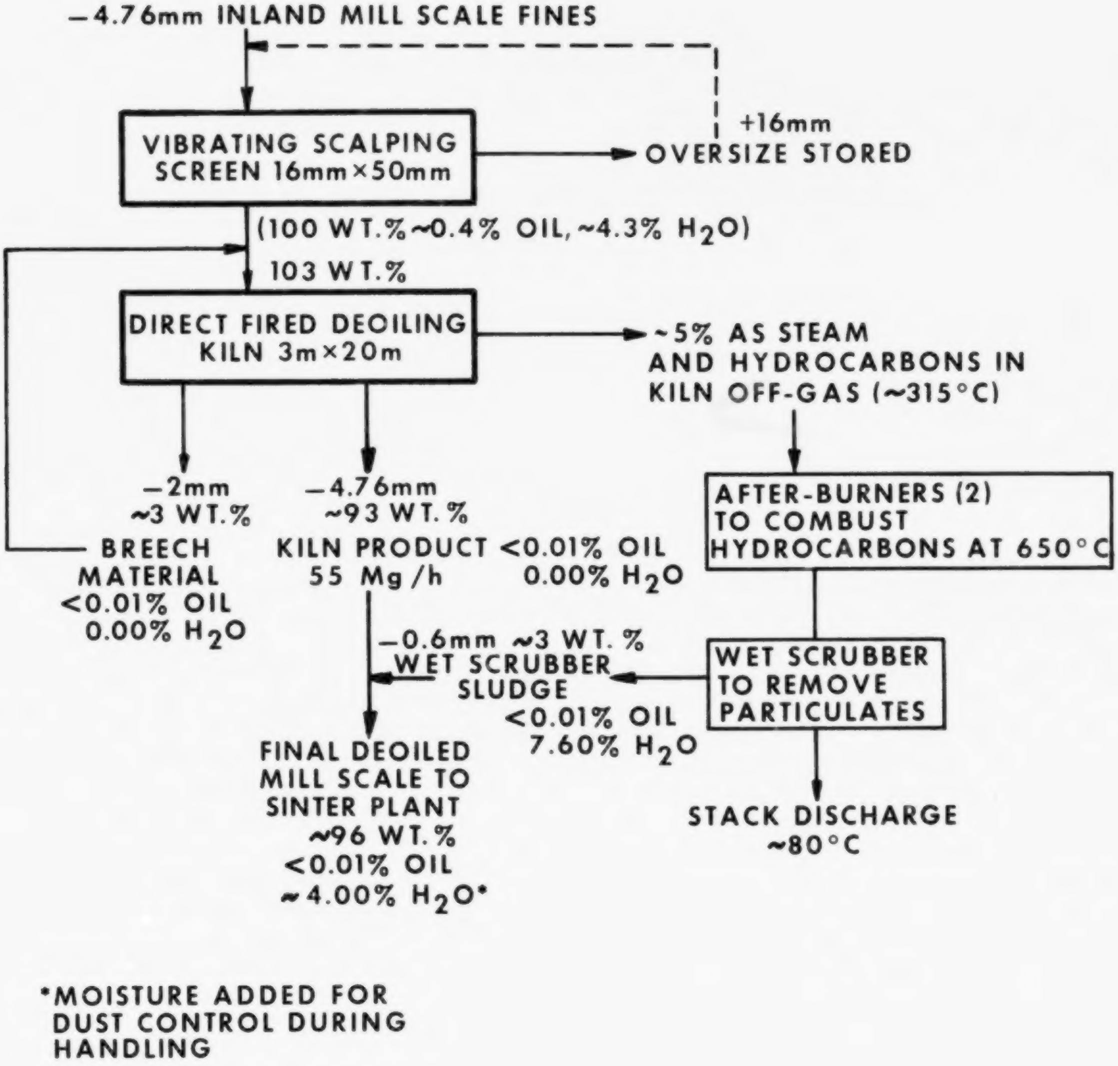


FIGURE 2 STATIC THERMAL DEOILING OF −4.76mm MILL SCALE FINES AS A FUNCTION OF DEOILING TIME AND TEMPERATURE



−4.76mm INLAND MILL SCALE FINES
VIBRATING SCALPING SCREEN 16mm×50mm
+16mm
OVERSIZE STORED
(100 WT.% ~0.4% OIL, ~4.3% H2O)
103 WT.%
DIRECT FIRED DEOILING KILN 3m×20m
~5% AS STEAM AND HYDROCARBONS IN KILN OFF-GAS (~315°C)
AFTER-BURNERS (2) TO COMBUST HYDROCARBONS AT 650°C
−2mm
~3 WT.%
BREECH MATERIAL
<0.01% OIL
0.00% H2O
−4.76mm
~93 WT.%
KILN PRODUCT
55 Mg/h
<0.01% OIL
0.00% H2O
−0.6mm ~3 WT.%
WET SCRUBBER SLUDGE
<0.01% OIL
7.60% H2O
WET SCRUBBER TO REMOVE PARTICULATES
STACK DISCHARGE ~80°C
FINAL DEOILED MILL SCALE TO SINTER PLANT
~96 WT.%
<0.01% OIL
~4.00% H2O*
*MOISTURE ADDED FOR DUST CONTROL DURING HANDLING

FIGURE 3 SCHEMATIC DIAGRAM OF COMMERCIAL DIRECT-FIRED KILN DEOILING OF INLAND MILL SCALE FINES

CHARACTERIZATION AND UTILIZATION OF STEEL PLANT FINES

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ABSTRACT

In the production of finished steel products, various waste oxide materials are generated (e.g., blast furnace flue dust, steelmaking dusts, and mill scale). The materials present serious environmental and resource recovery problems. Future environmental, space, and economic considerations will necessitate new handling and treatment methods for these materials. The quantity of waste oxide material generated each year by American steel producers is enormous. The contained iron content of the material is high and if recycled would reduce the quantity of virgin materials needed by industry. At present, however, problems associated with the dust materials make recycling to blast furnace or steelmaking operations quite difficult. Research is being conducted to characterize the dust materials and to develop processing methods which will allow greater utilization of these materials in our primary production processes. The physical and chemical properties of mill scale, blast furnace flue dust, and steelmaking dusts have been investigated. The various properties of the dust materials are given in this paper. The results of this preliminary work point to methods which may allow greater utilization of the materials in iron and steelmaking operations.

INTRODUCTION

In the production of finished steel products, various waste oxide materials are generated (e.g. blast furnace flue dust, steelmaking dusts, and mill scale). These materials present serious environmental and resource recovery problems. The amount of waste oxide material generated is dependent on both the quality of the materials used and the operating conditions employed in a given steel mill operation. The rates of waste oxide generation from various Inland operations are shown in Table 1. These values are based on long term plant experience. At its current raw steel capacity, Inland generates over 650,000 tonnes of waste oxide material each year. Since Inland's share of total raw steel production in the United States is approximately 6 percent, the total amount of waste oxide materials generated by American industry is enormous.(1)

Future environmental, space, and economic considerations will necessitate new handling and treatment methods for these materials. At present, however, problems associated with the dust materials make recycling to blast furnace or steelmaking operations quite difficult. Research is being conducted to characterize the dust materials and to develop processing methods which will allow greater utilization of these materials in our primary metal production processes.

The physical and chemical properties of Inland's mill scale, blast furnace flue dust, and steelmaking dusts have been investigated. The various properties of these materials are given in this paper. The results of this preliminary work point to methods which may allow greater utilization of the materials in iron- and steelmaking operations.

EXPERIMENTAL

Samples of mill scale, blast furnace flue dusts, and steelmaking dusts were investigated by various techniques. Chemical analyses were made using standard methods; the analytical results are reported on an elemental basis. X-ray diffraction analyses were performed using a Debye-Sherrer camera and chromium radiation. These techniques were supplemented by scanning electron microscopy, electron microprobe analysis, and optical microscopy.

The bulk densities of the dry-collected flue dusts and mill scale were determined by weighing the amount of material necessary to fill a 0.028 m^3 container; hand tapping was used to simulate settling. "Theoretical" densities were determined using a water pycnometer.

Particle size distribution analyses were made using various sizing techniques. Standard sieving techniques were employed for mill scale and dry-collected blast furnace flue dust. A Cyclosizer Sub-Sieve Analyzer was used to examine the wet-collected blast furnace flue dust and the -0.044 mm dry-collected blast furnace flue dust. The steelmaking dusts were investigated using a Model T_{AII} Coulter Counter.

Relative magnetic susceptibility measurements were made by means of a Satmagan saturation magnetization analyzer. "Percentage magnetic material" values were obtained as direct instrumental readings and are equivalent to that which would be obtained for samples containing various amounts of iron as magnetite dispersed in a magnetically inert material.

Other testing procedures such as magnetic separation, hydrocycloning, and froth flotation were also used.

RESULTS AND DISCUSSION

Mill Scale

This material accounts for approximately one third of the waste oxide material generated each year by Inland. It results from surface oxidation of ingots, slabs, and other steel materials in rolling and finishing operations. The surface oxide products fracture off the steel materials and are collected in scale pits. The scale is periodically cleaned from these pits and some is recycled to iron- and steelmaking operations. Usually the larger sizes (greater than 6.35 mm) are used directly in blast furnace operations. The smaller materials are often recycled through sintering operations. Any unused material is usually discarded into landfills.

The mill scale is a relatively coarse, dense, high iron content (e.g. 72.2 wt. % Fe) waste oxide material which is low in tramp impurities (see Tables 2-6). The material consists of metallic iron, various iron oxides, and gangue material. The predominant iron oxide phases are wustite and magnetite (see Table 2). Minor amounts of hematite are also present. The various phases found in the scale are shown in Figure 1.

The mill scale has a high degree of magnetic character, as shown in Table 3. This arises from the large quantities of metallic iron and magnetite present in the scale material.

Since the mill scale consists largely of metallic iron and partially oxidized iron oxides, a significant quantity of heat is released when the material is processed in sintering operations due to oxidation of these phases to hematite. The amount of mill scale used in sintering must be closely controlled to ensure efficient thermal operation of the sinter strand. If other materials containing significant amounts of fuel substances are also used in sintering operations (e.g. blast furnace flue dust), the amount of mill scale that can be used may be limited.

If a baghouse is used to control sinter plant emissions, the oil content of the mill scale must be reduced to prevent operating difficulties and to reduce possible air pollution problems. At Inland, the scale is de-oiled in a rotary kiln. The deoiling process effectively reduces the oil content to acceptable levels.

Since processing of the scale in sintering operations results in oxidation of the iron and iron oxide phases to hematite, some inefficiency is inherent in processing scale in this fashion. It may, therefore, be beneficial to consider other processing techniques that would maintain the original degree of oxidation of the scale. For example, if a suitable mill scale agglomerate could be produced with acceptable chemical and physical properties for direct use in ironmaking operations, the reduced energy requirement of the partially reduced iron oxides would result in lower coke rates and increased furnace productivity. Alternatively, if the scale could be treated in a direct reduction kiln, the low residual sponge iron produced would be useful in either steelmaking operations as a scrap substitute or in ironmaking operations where the coke rate would be reduced and furnace productivity increased.(2-4) Furthermore, the scale may be useful as a cooling agent in steelmaking operations. These possible alternatives need further technical and economic analyses to determine if they are indeed viable alternatives to current processing methods.

Blast Furnace Flue Dusts

At Inland, these dusts are the second largest contributor to the total amount of waste oxide material generated each year. There are two types of dust materials collected in blast furnace operations. Dry-collected dusts are obtained from cyclone dust collectors. The finer dust that escapes the cyclone collectors is caught by wet scrubbers. This wet-collected dust material is further processed in thickeners and filtering devices to reduce the water content. Currently, some of this material is utilized in sintering operations, but the bulk of the material is used as landfill.

Dry-Collected Dust. This material is a multi-component physical mixture of degraded blast furnace burden materials (e.g. coke, pellets, mill scale, BOF slag, ore, sinter, and limestone) with a variable chemistry. The complexity of the dust material is well illustrated in Figure 2 which shows typical examples of the various components. Coke, pellet, and BOF slag fragments are the predominant components of the dust material. The diversity of the mixture is reflected by the x-ray diffraction analysis of the dust material which shows that the significant phases present are hematite, magnetite, graphite, calcium carbonate, wustite, and silica (see Table 2).

The bulk density of the material is about half that of mill scale (see Table 5). This is largely due to the large quantity of coke fragments in the dust material. Quantitative microscopy shows that on a volume basis, coke fragments are the single greatest component of the mixture.

The chemical composition of the dust material depends on the strength of the burden materials used in the blast furnace operations. If coke quality is low, the dust material will be richer in carbon components. Furnace operation with low strength iron burden materials will result in an increased iron content for the dust material. The material averages 30.6 wt. % Fe and 31.3 wt. % C (see Table 4), but these values can vary by ± 10 wt. % in daily operation. The dust material contains undesirable concentrations of alkali, zinc, and lead impurities (see Table 4). The use of agglomerates produced from dusts containing high levels of these impurities may lead to blast furnace operating difficulties.(5-8)

The size distribution of particles in the dust material is broad and ranges from a top size of approximately 2.4 mm to less than 0.014 mm. Over 86% of the material is greater than 0.149 mm. All the components of the dust material can be found over the whole particle size range, but some segregation according to size can be seen (see Table 7). The carbon components concentrate in the coarser size fractions (over 70% of the total carbon in the dust is found in particle fractions greater than 0.149 mm). The iron components are more evenly distributed throughout the particle size range and only 50% of the iron components are greater than 0.149 mm. Most of the zinc material contained in the dust is found in the smaller size ranges (over 62% of the total contained zinc is found in the size fractions less than 0.149 mm).

Since the dust material is a physical mixture of diverse components, physical beneficiation of the material may be possible. This may allow for increased usage of the material in iron- and steelmaking operations. At the current time, the usage of flue dust in sintering operations is limited due to both the variability in dust composition and the high carbon levels in the dust. If these problems can be overcome through physical beneficiation, more of the material might be consumed in sintering. Preliminary studies using various physical separation techniques look promising in this regard.

Wet-Collected Dust. This material is similar to the dry-collected dust. Similar iron oxide, carbon, and gangue components are found in each (see Tables 2 and 4). The material contains some magnetic iron oxides, as indicated by x-ray diffraction analysis and Satmagan testing. The dust is generally smaller in size consist and contains more carbon than the dry dust (see Tables 4, 6, and 8). Over 68% of the material is less than 60.5 μm and 22% is less than 17.5 μm.

The wet-collected dust is concentrated in Dorr thickeners to an average water content of 58%. This water content is quite variable and may range from as low as 45% to greater than 70%. Consequently, the material must be dewatered prior to its use in sintering operations.

This material, like the dry-collected dust, has a variable chemistry. The material averages 23.8 wt. % Fe and 44.8 wt. % C, but these values can vary by ± 10 wt. % in daily operation. The high and variable carbon content of this material makes efficient use of the material in sintering operations quite difficult. In addition, the zinc content is higher than that of the dry-collected dust. This factor also limits the amount of wet-collected dust that can be recycled in sintering operations, because the amount of zinc entering the blast furnace must be limited to ensure efficient blast furnace operation, and the zinc content is not reduced significantly in sintering.

Like the dry-collected dust, segregation of some chemical species according to particle size was found for this dust material. Figure 3 shows that the zinc material concentrates in the lower particle size range; alkalis show the opposite trend. The Japanese have found a similar trend for their wet-collected flue dust.(9) They use this property to lower the amount of zinc in the dust materials processed for recycling by separating the smaller size materials from the bulk of the dust using a wet cyclone. They claim to eliminate between 70-80% of the original zinc in the dust material using this technique.(9) Some segregation of the carbon components was also found. As was found for the dry-collected dust, the carbon components concentrated in the larger particle size range.

Since the wet-collected dust is similar to the dry-collected material, some beneficiation of the material should be possible using physical beneficiation techniques. Some preliminary tests show that froth flotation may be useful in upgrading the dust to produce an iron concentrate more readily amenable to sinter plant treatment. Other uses for beneficiated dust materials are also being investigated.

Steelmaking Dusts

Steelmaking dusts account for the lowest proportion of waste oxide materials generated each year, but they may be the most difficult to recycle through iron- and steelmaking operations due to their fine size consistency and undesirable chemistry. The materials are formed during the melting and refining stages of steel production. They are evolved as a fine fume which is collected using electrostatic precipitators, baghouses, and scrubbers. The collected materials may be dry or wet depending on the collection system used.

Dry-Collected Dusts. At Inland, electric furnace dust and open hearth dust are collected in the dry condition using a baghouse and electrostatic precipitator, respectively. These dusts are similar in mineralogy, magnetic properties, and size consistency, but have somewhat different overall chemistries (see Table 2, 3, 4 and 9). X-ray diffraction analysis shows that the predominant phases in these materials are magnetite, hematite, and zincite. The materials are very fine (over 97% of the dust is less than 64 μm) and this causes difficulties in handling and transportation. The open hearth dust is richer in iron than the electric furnace dust (52.0 wt. % Fe versus 32.8 wt. % Fe). The zinc concentrations for these materials depend on the amount of zinc-bearing scrap charged to the furnace. When high levels are used, zinc concentrations for the dust may exceed 20 wt. %. Agglomerates produced from these dusts are unsuitable for use in ironmaking operations because of their high levels of zinc, lead, and alkali.

In order to increase the potential for recycling these materials, the amount of zinc contained in these dusts must be greatly reduced. Leaching and other tests indicate that roughly half the zinc exists as zincite. The remaining zinc material exists as zinc ferrites, silicates, and aluminates. The zincite form is easily leachable using acid or basic solutions. The other zinc forms will require more rigorous processing. Thermal treatment may be necessary to fully remove the zinc contained in these dust materials.

Wet-Collected Dusts. In both of Inland's BOF operations, venturi scrubbers are used to collect the fine dust material generated during steel production. Two different hood systems are used in the BOF operations. The older shop has the traditional open hood (OH) system which allows some air to mix with the off-gas. The newer shop has the closed hood off-gas (OG) system which prevents air from mixing with the off-gas stream. The off-gas from the OG system has a higher reduction potential than that from the OH system. Consequently, the iron oxide forms found in the BOF-OG dust are in a more reduced state (see Table 2). The predominant iron oxide phase for the BOF-OG material is wustite; whereas, for the BOF-OH material a mixed ion spinel (probably a mixture of magnetite and zinc ferrite) is obtained.

The chemistry of the dusts are similar (see Table 4). Both dusts contain over 52 wt. % Fe and 3-4 wt. % zinc. The zinc concentration in the dust material depends on the amount of scrap charged, as mentioned previously. The BOF materials have lower average zinc concentrations than the electric or open hearth dusts, because the amount of scrap used in BOF operations is substantially less and the scrap used is lower in zinc.

The two BOF materials have similar size consistencies (see Table 9). The size distributions of these dusts are comparable to those obtained for the electric furnace and open hearth dusts (over 97% of the material is less than 64 μm).

Several problems exist which prevent wide-spread recycling of this material. First, the zinc level, although greatly lower than that of the dry-collected dusts, is still too high for direct recycling to ironmaking processes. Second, the material must be dewatered prior to use in iron- or steelmaking processes. And, third, the material must be agglomerated (because of its fine particle size) prior to recycling into primary metal operations.

The first problem is the most difficult. The zinc is in a highly leachable state, in the case of the BOF-OG dust. Preliminary acid leaching tests have shown that the zinc exists largely as zincite for this material (almost 73% of the total zinc was soluble in acid solution). However, for the BOF-OH system, zinc ferrite phases predominate and only 22% of the total zinc was soluble in acid solution (pH = 1). Thermal processing may be necessary to fully remove the zinc in these dusts. After zinc removal, acceptable agglomerates can be made for use in iron- and steelmaking processes.(10-12)

SUMMARY

Various chemical and physical tests were conducted on blast furnace flue dust, mill scale, and various steelmaking dusts. The mill scale was found to be a relatively coarse, dense, high iron content waste oxide material which is low in tramp impurities. The scale largely consists of metallic iron and partially oxidized iron oxides.

The blast furnace flue dust materials were found to be a multi-component mixture of degraded blast furnace burden materials. The chemistry of these dusts is quite variable and this variability and the high carbon content of these dusts limits the use of the materials in current sintering operations. Various physical processing techniques are being investigated which should allow effective beneficiation of these materials into iron and carbon concentrates. These beneficiated materials may then be better utilized in iron- and steelmaking operations.

The steel plant dusts were found to consist of very fine particles and to have undesirable levels of zinc, lead, and alkali. The mineralogy of these dusts depends on the steelmaking operation employed. Removal of zinc from these dusts using hydrometallurgical methods will be difficult as significant amounts of zinc ferrites, silicates, and aluminates have been detected. Thermal treatment for zinc removal is feasible and will allow increased usage of these materials in ironmaking operations.

Test work is continuing on various beneficiation techniques which should allow further recycling of the various waste oxide materials in primary metal production processes.

REFERENCES

1. Anon, "1978 Steel Industry Financial Analysis," Iron Age, 222, (17), 1979, p. 36B.

2. Rollinger, B., "Steel via Direct Reduction," I & SM, January, 1975, pp. 10-15.

3. Bleimann, Karl R., and Ahmed, Aziz, "An Assessment of the Value of Direct Reduced Iron to the Steelmaker," Proceedings of the 3rd International Iron and Steel Congress, April 16-20, 1978, Chicago, Illinois, pp. 435-438.

4. Maschlanka, Walter, et al, "Utilization of Direct Reduced Iron in Iron and Steel Production Processes," Proceedings of the 3rd International Iron and Steel Congress, April 16-20, 1978, Chicago, Illinois, pp. 422-434.

5. Schroth, P., and Robinson, G. C., "The Effects of Alkali Attack on Various Carbon Refractories," Ironmaking Proceedings, 32, 1973, pp. 60-73.

6. El Kasabgy, T. and Lu, W-K., "Combinative Effect of Gangue and Alkalies on the Behavior of Iron Ore Pellets During Reduction," Ironmaking Proceedings, 36, 1977, pp. 2-8.

7. Sasaki, Minoru, and Nakazawa, Takao, "On the Mineral Composition and Formation of the Blast Furnace Scaffold," Trans. ISIJ, 9, 1969, pp. 413-422.

8. Chow, C. K., and Lu, W. K., "Degradation of Coke in the Blast Furnace Due to Alkali Vapors," Paper presented at 62nd National Open Hearth and Basic Oxygen Steelmaking Conference and 38th Ironmaking Conference, March, 1979, AIME, Detroit, Michigan.

9. Toda, Hideo, et al, "Blast Furnace Wet-Dust Zinc Removing Installation Using Wet Cyclone and Its Operation," Tetsu-to-Hagane, 64, (8), 1978, pp. 78-A91-78-A94.

10. Kanda, Y., et al, "Production of Pre-Reduced Pellets from Iron and Steelmaking Dust," Tetsu-to-Hagane, 62, Lectures 9 and 10, S9 and S10.

11. Saito, Y., "Direct Reduction Process for Recycling Steel Plant Waste Fines," Ironmaking Proceedings, 34, 1975, pp. 464-481.

12. Sugasawa, K., et al, "Direct Reduction of Metallurgical Dusts," Stahl und Eisen, 96, (24), 1976, pp. 1239-1245.

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TABLE 1 APPROXIMATE GENERATION RATES OF INLAND WASTE OXIDE MATERIALS

Material	Generation Rate
Blast Furnace Flue Dust	40 kg/tonne HM
Mill Scale	36 kg/tonne RS
BOF Dust	14 kg/tonne RS
Electric Furnace Dust	18 kg/tonne RS
Open Hearth Dust	11 kg/tonne RS

HM = Hot Metal; RS = Raw Steel

TABLE 2 X-RAY ANALYSIS OF VARIOUS WASTE OXIDE MATERIALS

Material	Major Phases	Minor Phases
Mill Scale	$Fe_{1-x}O$ Fe_3O_4 Fe	α-Fe_2O_3 $CaCO_3$
Dry-Collected Blast Furnace Flue Dust	α-Fe_2O_3 Fe_3O_4 C (graphite) $CaCO_3$	$Fe_{1-x}O$ SiO_2
Wet-Collected Blast Furnace Flue Dust	α-Fe_2O_3 Fe_3O_4 C (graphite) $CaCO_3$	$Fe_{1-x}O$ SiO_2
Electric Furnace Dust	Fe_3O_4 ZnO α-Fe_2O_3	
Open Hearth Dust	Fe_3O_4 α-Fe_2O_3 ZnO	
BOF-OG Dust**	$Fe_{1-x}O$ Fe_3O_4 Fe	$CaCO_3$
BOF-OH Dust**	$(Fe_{1-y}X_y)\ Fe_2O_4$* $CaCO_3$	α-Fe_2O_3 $Fe_{1-x}O$

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* Mixed Ion Spinel — Some Zinc Ferrite may be present.

** BOF-OG = (BOF operating with Closed Hood Off-Gas System.)
BOH-OH = (BOF Operating with Open Hood System.)

TABLE 3 RELATIVE MAGNETIC CONTENT OF VARIOUS WASTE OXIDE MATERIALS*

Material	Magnetic Material (wt. %)	Fe Content for Sample Tested (wt. %)
Mill Scale	48.0	76.8
Dry-Collected BF Flue Dust**	3.2	23.6
Wet-Collected BF Flue Dust**	4.6	21.6
Electric Furnace Dust	14.6	35.8
Open Hearth Dust	29.9	58.2
BOF-OG Dust***	3.0	58.6
BOF-OH Dust***	44.4	52.1

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* Magnetic Determinations by Satmagan Analyzer

** BF = Blast Furnace

*** BOF-OG = (BOF Operating with Closed Hood Off-Gas System.) BOF-OH = (BOF operating with Open Hood System.)

TABLE 4 AVERAGE CHEMICAL ANALYSIS OF VARIOUS WASTE OXIDE MATERIALS (Wt. %)

Species	Mill Scale	BF Flue* Dust (Dry)	BF Flue* Dust (Wet)	OH Dust*	EF Dust*	BOF-OG** Dust	BOF-OH** Dust
Fe	72.2	30.6	23.8	52.0	32.8	57.4	52.8
Fe(met)	1.2	ND	ND	ND	ND	ND	ND
Fe^{++}	48.5	12.8	5.5	1.7	1.1	36.2	16.5
Fe^{+++}	22.1	ND	ND	ND	ND	ND	35.8
C	ND	31.3	44.8	ND	0.3	ND	ND
Si	0.4	3.0	3.0	0.2	1.1	0.9	0.8
Al	0.7	0.9	1.1	0.1	0.3	0.1	0.2
Ca	1.4	5.1	3.8	1.0	6.6	4.2	6.4
Mg	0.1	1.2	1.1	0.4	1.6	0.7	1.6
Mn	0.5	0.6	0.3	0.5	3.5	1.3	1.1
S	0.05	0.5	0.4	1.4	0.5	0.2	0.3
Zn	ND	0.1	0.4	10.6	10.3	3.2	4.1
Pb	ND	0.1	0.1	1.2	2.1	1.0	0.4
Na	0.1	0.1	0.1	0.5	0.9	0.1	0.1
K	ND	0.3	0.2	0.7	1.0	0.1	0.1
P	0.03	0.1	0.1	0.1	0.1	0.1	0.1
VM	ND	14.9	ND	ND	ND	ND	ND
Oil	0.5	0.02	ND	ND	ND	ND	ND

ND = Not Determined

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* BF = Blast Furnace; OH = Open Hearth; EF = Electric Furnace

** BOF-OG = (BOF operating with Closed Off-Gas Hood System)
BOF-OH = (BOF operating with Open Hood System)

TABLE 5 "THEORETICAL DENSITY" AND BULK DENSITY MEASUREMENTS FOR VARIOUS WASTE OXIDE MATERIALS

Material	"Theoretical" Density (kg/m^3)	Bulk Density (kg/m^3)
Mill Scale	4300	2130
Dry-Collected BF Flue Dust*	2700	980
Wet-Collected BF Flue Dust*	2100	-
OH Dust*	4400	1130
EF Dust*	3600	900
BOF-OH Dust**	3500	-
BOF-OG Dust**	3000	-

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* BF = Blast Furnace; OH = Open Hearth; EF = Electric Furnace.

** BOF-OG = (BOF operating with Closed Hood Off-Gas System)
BOF-OH = (BOF operating with Open Hood System)

TABLE 6 SIZE DISTRIBUTION FOR MILL SCALE AND DRY-COLLECTED BLAST FURNACE FLUE DUST

Screen Aperture Size (mm)	Percentage Less Than Size Indicated	
	Mill Scale*	BF Flue Dust
2.38	92.2	96.6
1.68	-	95.0
1.41	83.8	-
1.19	-	92.9
1.00	72.0	-
0.84	-	89.3
0.59	67.4	81.6
0.42	-	62.2
0.297	31.2	49.8
0.210	17.0	30.2
0.149	7.8	13.7
0.074	6.3	13.5
0.044	0.5	6.2
0.036		4.3
0.026		3.1
0.018		2.2
0.014		1.3

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* This size analysis is for material processed through sintering operations.
BF = Blast Furnace

TABLE 7 SEGREGATION OF IRON, CARBON, AND ZINC SPECIES ACCORDING TO SIZE FOR DRY-COLLECTED BLAST FURNACE FLUE DUST

Screen Aperture Size (mm)	Chemical Analysis of Incremental Size Fractions (wt.%)			Cumulative Percentage of Total Species Contained in Particles Greater than Size Indicated		
	Fe	C	Zn	Fe	C	Zn
+0.59	11.0	63.8	0.05	0.5	2.6	0.4
0.297	16.6	50.0	0.08	8.0	25.3	8.2
0.210	27.2	33.7	0.09	25.0	46.3	19.9
0.149	28.8	31.5	0.10	48.3	71.1	37.1
0.074	32.8	28.5	0.11	63.4	84.5	47.3
0.044	27.0	21.4	0.22	77.1	95.3	70.7
-0.044	57.8	10.8	0.35	100.0	100.0	100.0

TABLE 8 SIZE DISTRIBUTION FOR WET-COLLECTED BLAST FURNACE FLUE DUST*

Nominal Particle Diameter (μm)	Weight Percentage Less Than Size Indicated
60.5	68.8
46.7	38.9
33.0	30.4
22.7	24.7
17.5	22.0

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* Cyclosizer Sub-Sieve Analyzer Used for This Analysis.

TABLE 9 PARTICLE SIZE DISTRIBUTION FOR STEELMAKING FLUE DUSTS*

Flue Dust Source	Weight Percent of Total Dust Greater Than Particle Diameter							
	3 μm	4 μm	5 μm	6 μm	8 μm	16 μm	32 μm	64 μm
Open Hearth Dust	100.0	78.8	65.0	54.0	44.4	21.0	9.9	1.6
Electric Furnace Dust	77.8	66.3	59.1	53.1	47.8	34.5	19.8	2.2
BOF-OG Dust**	80.3	68.7	60.0	52.1	45.3	28.8	13.4	2.5
BOF-OH Dust**	82.6	70.1	60.5	53.5	48.4	33.2	16.5	2.9

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* Coulter Counter Model T_{AII} Used for this Analysis.

** BOF-OG = (BOF Operating with Closed Hood Off-Gas System)
BOF-OH = (BOF Operating with Open Hood System)

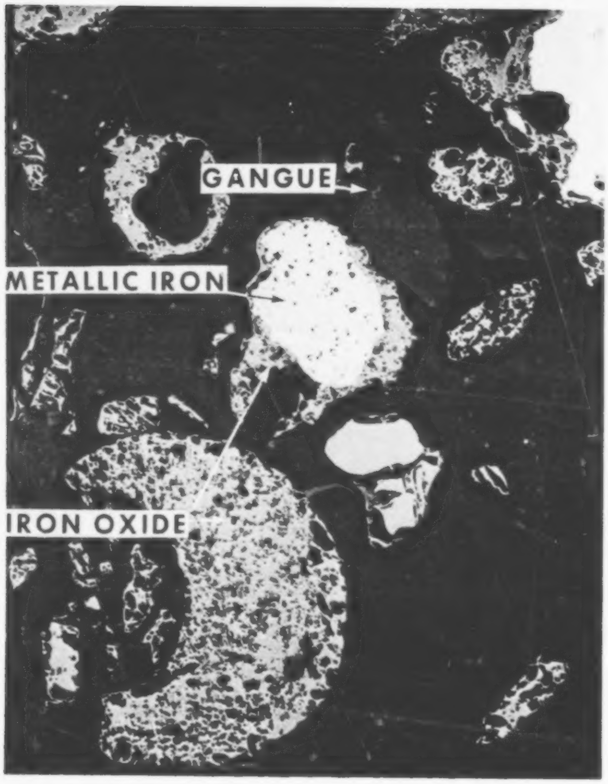
GANGUE
METALLIC IRON
IRON OXIDE
200 μm

FIGURE 1 SINTER PLANT MILL SCALE-100X

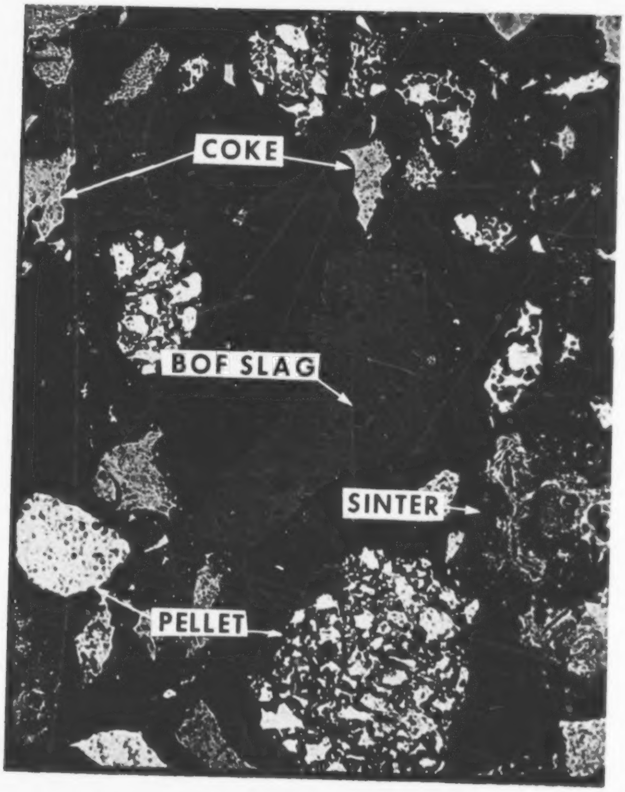
COKE
BOF SLAG
SINTER
PELLET
200μm

FIGURE 2 DRY-COLLECTED BLAST FURNACE FLUE DUST-100X

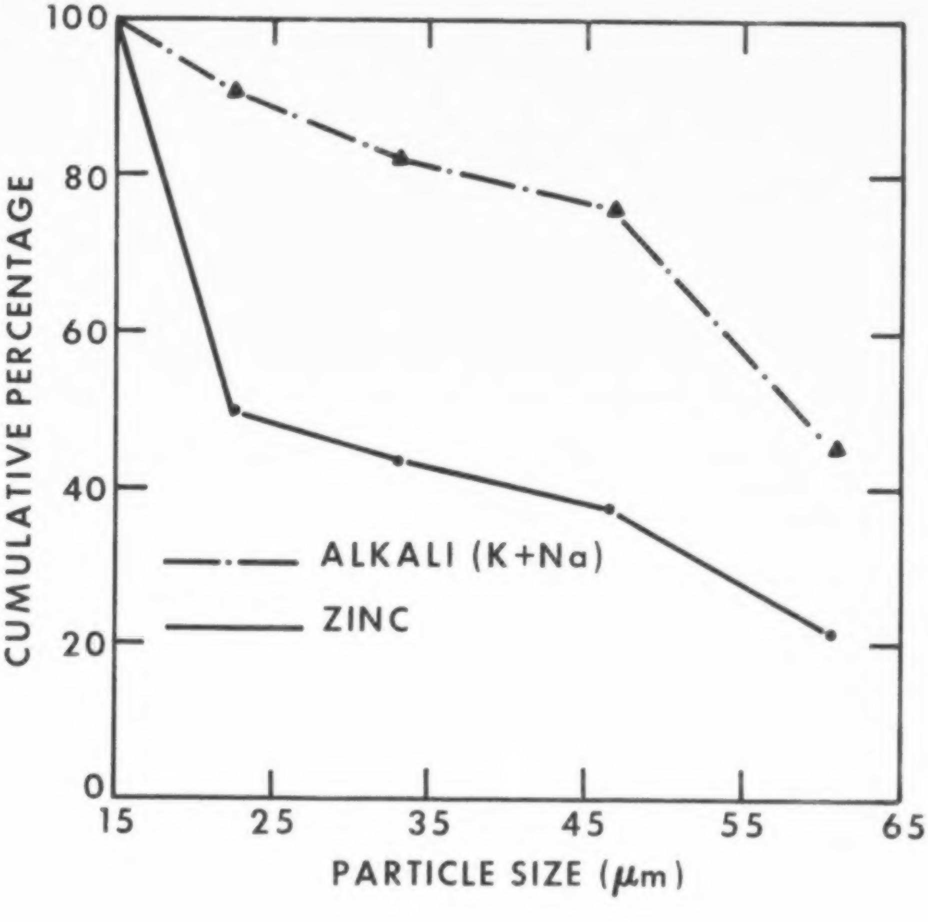

FIGURE 3 CUMULATIVE PERCENTAGE OF TOTAL SPECIES CONTAINED IN PARTICLES GREATER THAN SIZE INDICATED FOR WET-COLLECTED BLAST FURNACE FLUE DUST

INTERNATIONAL MINERAL RECOVERY, LTD., DEZINCING PROCESS

by

John E. Allen
President
International Mineral Recovery, Ltd.

ABSTRACT

The basic intent of the Process is primarily for processing steelmaking dusts containing low amounts of zinc and lead in combination with higher iron values.

Because of well founded problems in recycling the steelmaking dusts through normal steel plant dust agglomeration facilities and the blast furnace a new method has been developed.

The Process follows the lines of a previously developed process for the binding together of ferrogenaceous and carbonaceous substances with a heavy hydrocarbon binder. Further treating of the agglomerates produces a strong product for further processing in high temperature facilities to effect the separation. The Process is covered by U. S. Patent No. 3,850,613.

Specific handling steps begin with conventional receipt of materials in bins and proportioning by adequate feeding arrangements. All materials are well blended and dried in conventional equipment.

Binder addition and briqueting are done at +200 °F using a conventional roll type briquet machine. Dehydrogenation of the binder is accomplished in a stream of hot air.

Final processing is done in conventional iron making cupola or electric arc furnace with the amount of carbon in the raw dusts being the determining factor.

Conventional high efficiency dust collectors capture the zinc and lead oxides, while the molten iron is pigged in conventional pig machines. And, slag is air cooled for shipment to the usual processors.

INTERNATIONAL MINERAL RECOVERY, LTD., DEZINCING PROCESS

By John E. Allen, President

The primary intent of this Process is for the removal of zinc from steelmaking dusts. And, it applies to other zinc and iron bearing substances. Lead to a small percentage is also associated with zinc as both are found in scrap which is used as a portion of every steelmaking process. The analysis of the major tonnages of steelmaking dusts is as follows: Fe 35 - 60%; Zn 1.2 - 20%; Pb 0.2 - 2%; S 0.03 - 1.7%; SiO_2 1 - 2.5%; and, CaO & MgO 2 - 15%.

The first characteristic limiting recycle of these steelmaking dusts through normal channels is the zinc content, which causes disintegration of the blast furnace refractory linings. And, sintering plants, the normal agglomeration facility used in steel plants, experiences operating difficulties with these primarily submicron sized particles.

The problems presented by the steelmaking dusts inside the steel plants and the surrounding communities became urgent with the advent of oxygen steelmaking. With the old basic open hearth process with its white to yellowish emissions were considered just a nuisance and the emissions were carried away by the air currents and spread over a very wide area. Oxygen steelmaking, however, brought about the dense red clouds of dust in spectacular amounts over a short period of time. Thus they required installation of gas cleaning equipment. The dusts containing the oxides of heavy metals had to be disposed of with other forms of "in-plant" debris. While the generation of unsightly steel plant waste materials has been common practice for many years, it wasn't until these new steelmaking dusts were added that another potential problem was detected. An investigation by the United States Enviromental Protection Agency showed that the zinc and lead contents of these dusts could be leeched out into the natural waterways under specific conditions. These findings were published in February, 1977 under EPA 600-2-77-044.

The extraction of zinc and lead is by no means new. Leeching is a well known technique and numerous patents have been granted employing this technology. The leeching technology when applied to steelmaking dusts, costwise, seems to 'break-even' around a zinc content of 12 - 15%. However, only a very minor tonnage of steelmaking dust ever reaches zinc contents this high. The bulk of the tonnage is in a zinc content range of 3 - 7%, with no guarantee of any degree of consistancy, and of course iron is the major metallic substance.

The thermal extraction of zinc from its ores has been practiced for centuries by blending in an appropriate amount of carbon and heating same in an enclosed vessel. One early process of 'our time' has been the horizontal retort which collected metallic zinc in a condenser, while any iron remained in the retort as a residue along with excess carbon, small percentages of lead and zinc, and gangue materials, all of which was wasted in a dump. These dump areas still dot communities where these plants once operated. The process was discontinued because emissions from these plants killed plant life in the communities where these plant operated so that large tracts of land were devastated. Utalizing the same technology, the vertical retort was devised, but without the devastation problem. Hence, at least two thermal methods are well proven for the extraction of zinc.

Our analysis, based upon the study of various processes and their economics, led us to believe that all components must be salable products, in order that the Process be economically viable. Zinc being the smaller percentage must be considered a coproduct. Iron, in order to bring the maximum return, must be in a form capable of bringing the highest price. Steel, we analysed required a major investment for a very minor tonnage. Pig iron on the other hand is a top dollar product which can be produced easily. And, a third product, slag, is salable as an aggregate. Hence, we could see that our Process was one producing products all of which were salable.

Work done on earlier dates for the agglomeration of waste fines from steel plants had indicated that strong agglomerates could be made which retained all the metallic and carbon values, while providing good strengths at high temperatures. The process utalizes a heavy hydrocarbon binder and the processing of same in hot air. Test agglomerates were made of selected blends of zinc and iron dusts plus coke dust and heated same in a muffle furnace. Zinc vapors came off in a very short time and it was evident that we had a process which would work. Further work lead to the filing for a patent in late 1973, which was granted on November 24, 1974, as U. S. Patent No. 3,850,613.

I believe that at this point it might be well to stop and look at the modern day trends in a changing society.

It seems apparent that the accumulation of solid wastes are becoming an ever increasing cost problem. As communities grow the land available in close proximity to the industrial sector for dumping waste materials is disappearing, hence, disposal costs are increasing. Furthermore, the toxic materials which have been highlighted in numerous news releases causes adverse public reactions to any dump situation so that permits for new dump sites are increasingly difficult to obtain. There is no doubt that dumps over the years have been unsightly. Pressure seems to be toward the cleanup of many such dumps and certainly to gain insurance that any future dumps be 'beautified' will simply mean that extra costs can be expected.

Another factor which is just beginning to reach the 'headlines' is the growing scarcity of metals in the United States. An article appearing in the July 2, 1979 issue of BUSINESS WEEK states that this shortage will have an even greater impact on costs than the Energy Crisis. Recycle of metallics in the steelmaking dusts will help.

The combination of the increasing dump costs and the scarcity of metals bring out a new need for reacessing our wastage practices. It is our belief that into process costs must be taken the full concept of processing all segments. The old concept of processing that protion which represented the major profit and dumping the rest on the 'back 40' is coming to a close. And, since it is a well established fact that "matter is never destroyed, but only changed", we have sought by this Process to bring about change without increasing existing costs.

We believe that the Steel Industry have and will continue to seek out corporations who have special skills in handling waste substances. There operates today numerous corporations which have built up reputations of service in handling large amounts of waste substances such as slag and scrap metallics. We believe that more sophisticated processes will be required as work toward total processing becomes a 'must'. It is into this category that our Dezincing Process falls.

We fit where dusts containing zinc and lead are intermingled with iron bearing substances and where mechanical separation is impossible. With the original intent based upon the solution of the current production of steelmaking dusts, we have found that it may be profitable and necessary to also consider dusts previously segregated and stocked or dumped with refuse, plus substances from other industries that contain zinc, lead, iron and carbon values.

Each situation is generally sufficiently different that the economics require individual evaluation in order to determing the profitability.

The Process integrated into a complete plant consists of the following:

Materials received consist of dusts of various size and moisture content. The method of receipt may be either by rail, truck, barge or belt. Steelmaking dusts maybe bone dry as received from precipitators, bag filters or cyclones. Or, as a filter cake or sludge from vacuum filters, centrifuges, or settling ponds. Hence, the moisture may vary from 0 to 50%. In actual practice there will generally be a variety of dusts with as many varied moisture contents. Also, of importance is the particle size of the various dusts. As a result we have found it to be most desirable to proportion these individual dusts with special feeders so that a controlled blend is achieved. It is further most important that the blend be thoroughly mixed so that it is homogeneous.

The homogeneous blend of proportioned dusts must be dried first to remove the moisture and secondly to preheat these materials to 200 - 225 °F so that the binder may be mixed into the dry dusts. After drying the materials can be easily screened. The plus 1/8" materials should be crushed. The minus 1/8" materials are now stored as a process surge point.

Binder should have a ring and ball softening pint below 212 °F. The binder may be heated to as much as 400 °F in order to secure the best mixing. Generally the dry dust mixed with the binder still appears dry and only slightly darker in color. Should excess binder be added such is uneconomical hence good control is needed. Moisture content is a further serious factor because of drying costs.

While we have indicated binder and moisture content, carbon content is indeed a major cost factor. Since this is a reducing process, carbon to reduce the zinc, lead and iron oxides is necessary as a first consideration. Secondly, this is a smelting process, hence heat must be provided for melting iron and slag for a quality pig iron and a slag capable of containing the sulfur. Hence, we are looking for an iron temperature of 2650 - 2750 °F in the melting unit. Because of this heat requirement the carbon content must first be the minimum to remove the oxygen from the metallic oxides. And, the heat required for smelting may be furnished by combustion of carbon contained in the brieuet, or added by combustion of fuel added along with the briquets, or electrical energy. Since carbon fines is mixed with many iron-zinc bearing dusts such is the least expensive method of obtaining the heat required. Should additional heat be required such can be in the form of coke dust added with the dust mix.

Briqueting is by a standard roll type briquet machine. The shape of the briquet is of importance as +40% voids is required. We have found that a 1½ X 1½ X 1 inch briquet is a good compromise in size vs cost consideration.

"Green" briquets are weak, hence a minimum of handling is essential. Again the presence of fines reduces the voids, hence, screening must be done. Again extreme care is required in charging the briquets on to the hot air processing conveyor line. Once placed on the conveyor line for processing with hot air no movement of the briquets takes place until the binder has been dehydrogenated.

This dehydrogenation process consists of converting the hydrocarbon binder to char by oxidizing off the hydrogen by the stream of hot air. The process generates heat so that the stream of air passing through the briquets both heats the briquets to the temperature that the reaction takes place and cools the briquets to a point that char does not ignite. Hence, the importance of a good void pattern and temperature control is a key factor in the process.

Cured briquets possess good strength, 600 - 800 lbs crushing strength. Thus, they may be screened thoroughly at ½" and all fines recycled back through the process. The +½" sized cured briquets are stored in bins for further processing at this logical surge point in the total process.

At this stage in the process it seems appropriate to discuss the pollutants from the process that may occur and must be handled.

In the transporting of the dusts 'drip' of the wet dusts from cars and trucks must be given careful attention. Bone dry dusts must be handled in enclosed containers. And, as all of us know who have handled these substances over the years, housekeeping in the unloading area is difficult and a constant chore.

At the processing plant, for those bins receiving the bone dry dusts adequate suction around the dumping area is necessary to capture such dusts that become airborne and collection of same in a bag filter. As previously discussed the proportioning and mixing of all dusts provides us with a material that is not difficult to handle. Drying produces a moisture vapor cloud which exits through the main stack, but no other substances are carried out when using a dryer consisting of the hollow screw design with high temperature oil circulating in the screws, as there is not sufficient agitation to have the particles become airborne. Each transfer point in the belt conveyor system must be hooded and connected to a bag filter. The same coverage is required for the dry dust screen, oversize crusher, and surge bin, as well as the heat treated briquet sizing screen.

The hot air processing of the 'green' briquets with its high volume of hot air generates some hydrocarbon smoke from the light distillates which exist in the binder and lubricating oils present in some dusts. The exhaust gases are used as combustion air for the hot oil heater, with any excess consumed by a thermal incinerator. The products of combustion from the hot oil heater exit with the moisture cloud from the dryer to improve the dew point.

Briquets are drawn from several bins by a program to provide a uniform analysis for the dezincing and melting unit. As previously discussed the type of melting unit depends upon the amount of carbon available from the various dusts, and determined by a study as to the best economic picture. In a high percentage of the studys made a cupola is the most practical melting unit.

A cupola melting unit consists of: skip charging, gas cleaning, hot blast, and runout systems. In the cupola the zinc comes off in the top region as zinc oxide which is swept out with the gas stream. This zinc rich dust is partially collected by a hot cyclone, with the balance collected by a final high efficiency collector. This zinc oxide rich dust is one of the salable products. A typical analysis is as follows: Zinc - 63.3%; Lead - 6.9%; Iron - 1.2%; Acid solubles - 3.6%; Tellurium - 0.28%; Tin - 0.05%; Cadmium - 0.1%; and, other substances 0.01% or less. However, it must be remembered that the analysis of each plant differs and though our information does not have a long history may vary over a long period as the materials charged into the steelmaking furnaces differs.

From the tap hole and into the skimming box flows the molten iron and slag where the slag is skimmed off and flows into a pit for cooling. The molten iron flows into a fore-hearth where any needed ferroalloys are added to adjust for silicon, manganese or phosphorous requirements. From the fore-hearth the molten iron flows into the pouring box of the pig machine. Pig iron is the largest volume product. Pig iron is handled by magnets for shipment or stocking for future shipment. The cooled slag from the pit is dug and loaded into trucks for shipment to aggregate merchandisers for sale.

This melting process of course produces some pollution which must be taken care of. The first being the top gases as has been covered in the above discussion. Where water cleaning is employed in the high efficiency scrubber the water from same will be processed through a settling pond and recycled. And, the smoke and graphite from the slag and iron runout will be hooded and the particles captured in a bag filter.

While it may not be essential it is our plan that at least for the first installation the whole operation will be contained inside a building so that the entire building may be evacuated through a bag filter system in order that if any of the air cleaning units fail or experience surges beyond the design capacity the individual systems will be 'back stopped' by the building evacuation system.

In conclusion we feel we have by the Process and the plant design strived to accomplish the beliefs stated in the beginning, namely that a waste substance be converted to all salable productts.

Closing Remarks - Norman Plaks

Chief, Metallurgical Processes Branch

IERL-RTP-EPA

During the past two and one-half days twenty-six speakers have discussed a wide range of pollution abatement technology topics relating to the iron and steel industry. We have heard discussions of advances in technology that have been made, of problems that are remaining and of new problems emerging.

We were told by the AISI that almost every new, major environmental control installation made by the industry is actually a prototype and becomes, in fact, a full scale development program. Several of the papers presented here tend to support that theory.

A presentation was made by EPA about it's role and attempts to operate a R&D program benefiting both the Agency and industry in the face of the industries' high capital intensiveness and the relatively low funding levels available. Joint-funding arrangements involving both EPA and the industry were present in a number of projects.

Some of the speakers recounted the environmental conditions of the industry in the past and the advances that have been made. Credit must be given to the industry for these advances.

However, it is apparent that we still have a long way to go, especially with respect to hazardous pollutants.

We have heard both here and elsewhere that economic conditions within the industry make it difficult for the industry to undertake research and development on the broad front that will be necessary to solve these problems.

Engineering and consulting firms and equipment suppliers have played a major role in the development of the pollution abatement technology. However they can not be expected to take on the burden by themselves.

One area that has not been discussed to any significant degree at this symposium is the role of innovative process technology. What I am talking about is new production process technology which minimizes the discharge of pollutants while simultaneously increasing the efficiency and lowering the cost of the iron and steelmaking process.

In summary there have been major and significant advances made in abating pollution from the iron and steel industry. There are still both remaining and newly emerging problems requiring solutions. Neither the industry, equipment supplies, engineering and consulting firms, or the Government can individually fund and solve these remaining problems especially if innovative technology is considered.

As a closing thought I would like to issue a challenge to the industry, to the equipment suppliers and consultants, and to the Government to continue discussing, planning, and then in unison implementing programs that will make it possible for the iron and steel industry to meet the environmental control needs in the most cost-effective manner.

UNPRESENTED PAPERS

Air Pollution Emissions Characterization of a Coal Preheater
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AIR POLLUTION EMISSIONS
CHARACTERIZATION OF A COAL PREHEATER

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ABSTRACT

The body of information presented in this paper is directed to those individuals concerned with current research efforts into quantifying gaseous and particulate emissions from coal preheat systems at coke plants.

Emission test results on a Coaltek Pipeline Charging System using a Cerchar coal preheater at a steel plant in Pennsylvania are presented. The primary objective of this EPA-sponsored research project was to investigate the inlet and outlet of the system's venturi scrubber for particulate and polycyclic aromatic hydrocarbon emissions.

Non-chloroform soluble particulate emission rates (front and back half) at the venturi scrubber outlet ranged between 0.256 - 0.281 pounds per ton of coal feed. Chloroform soluble particulate emission rates at the venturi scrubber outlet (front half, back half, silica gel) ranged between 0.215 - 0.549 pounds per ton of coal feed.

Gas Chromatography/Mass Spectrometry analysis indicated that scrubber removal efficiency of selected POM organic species was highly variable, ranging from 41.2% - 79.1% depending upon process operating conditions. On comparing coal preheater POM emission levels to Discharge Multimedia Environmental Goal (DMEG) values, the DMEG levels were exceeded for phenanthrene, benz(a) anthracene, benzo(a) pyrene, 7,12-dimethyl benz(a)anthracene, and 3-methyl cholanthrene.

EPA Level I organic analysis indicated that aliphatic hydrocarbons, fused aromatic hydrocarbons, phenols and esters were the major components in the stack air samples and aliphatic hydrocarbons, carbazoles and phenols in the water samples.

SUMMARY

An EPA-sponsored research project to characterize particulate and polycyclic organic material (POM) emissions in the effluent from a coal preheat system on a coke battery was conducted in August, 1978 at a steel plant in Pennsylvania. Effluents were sampled upstream and downstream of a venturi scrubber during various preheat system operational modes, including varying coal feed rate and preheater outlet temperature. Evaluation of chloroform soluble and non-chloroform soluble particulate emission rates was performed using a conventional EPA Method 5 train. A POM train was used for POM collection. The POM sampling train was essentially a Method 5 train with an adsorbent sampler located downstream of the filter and condenser and upstream of the impingers. Analysis was performed using Gas Chromatography/Mass Spectrometry.

Non-chloroform soluble particulate emission rates (front and back half) at the venturi scrubber outlet ranged between 0.256 - 0.281 pounds per ton of coal feed. Although the data base was not sufficiently large to statistically validate conclusions a number of trends were evident. Increasing the coal feed rate appeared to increase the wash and filter catches. Increasing the pre-heater outlet temperature appeared to increase the impinger catch. Overall scrubber efficiency (at 20 in. W.C. pressure drop and an L/G of 8) was approximately 90%, with relatively high removal efficiency in the front half of the train and relatively low removal efficiency in the back half of the train.

Analysis was also made for chloroform soluble particulate. Emission rates at the venturi scrubber outlet ranged between 0.215 - 0.549 pounds per ton of coal feed. Total particulate emissions (including both chloroform soluble and non-chloroform soluble particulate) from analysis of the complete sample train were 0.471 - 0.813 pounds per ton of coal feed. Front half train total particulate emissions (EPA Methodology) ranged from 0.191 - 0.280 pounds per ton of coal feed. Front half and back half (less silica gel) train total particulate emissions (DER Methodology) ranged from 0.425 - 0.752 pounds per ton of coal feed.

The GC/MS analysis showed that the scrubber removal efficiency on selected POM organic species was highly variable, ranging from 41.2% - 79.1% depending upon process operating conditions. In general, POM emissions increased with increasing coal feed rate. Among the compounds analyzed, the most prevalent species found were naphthalene, anthracene and phenanthrene. Lesser amounts of fluorene, pyrene, fluoranthene, benzanthracene, chrysene and benzopyrenes were also found. Discharge Multimedia Environmental Goal (DMEG) levels were exceeded for phenanthrene, benz(a)anthracene, benzo(a)pyrene, 7,12-dimethyl benz(a)anthracene, and 3-methyl cholanthrene. None of the species found in the scrubber inlet/outlet water samples exceeded their DMEG values. The GC/MS analyses showed that, in general, the levels of the selected organic species were higher in the inlet stack samples.

The selected POMs and their isomers represented about 2 to 7% (by weight) of the total organics collected in the sample. EPA Level I organic analysis indicated that aliphatic hydrocarbons, fused aromatic hydrocarbons, phenols and esters were the major components in the stack air samples and aliphatic hydrocarbons, carbazoles and phenols in the water samples.

INTRODUCTION

The concept of utilizing preheated coal is currently an attractive solution to improve throughput quality and economy in the coke-making operation. One such scheme is the Coaltek pipeline charging system with Cerchar preheater (refer to Figure 1). In this particular system, wet coal is withdrawn by screw conveyor from existing coal storage lines, sized and fed to the preheater by a variable speed screw. The wet coal is fed into a flash drying entrainment section where it comes into contact with a stream of hot oxygen-free gas. The gas carries the partly dried, entrained coal up through the preheater. In the combustion chamber, low-sulfur coke oven gas is burned stoichiometrically with air for complete combustion. The hot gases leaving the combustion chamber are a mixture of freshly burned gas and recycled products of combustion. The mixed gases leave the combustion chamber with a temperature range from 725°F to 1200°F, and pass through the venturi section of the preheater. The wet coal is pushed into this high volume gas stream by the feed screw. Temperature at the upper end of the flash-drying section (preheater outlet) is in the 500°F range. All preheated coal goes overhead and is recovered in primary and secondary conventional cyclone separators. Hot coal from the bottom of the cyclones is distributed to charge bins and fed by a specified charging sequence through pipelines to the ovens. Gas from the outlet of the secondary cyclones is split into two streams. Gas volumes equivalent to the combustion gases and moisture driven off the coal go to a venturi scrubber for cleaning before being exhausted to the atmosphere. The remaining gas volume is boosted in pressure by means of a recycle blower and then returned to the combustion chamber where it is used to temper and add to the flow of combustion gases passing up through the preheater. Automatic controls adjust the pressure differential across the secondary cyclones to maintain the desired flow of gases through the preheater.

PROGRAM OBJECTIVE

In an effort to better understand the nature of the emissions from the coal preheat system, the Environmental Protection Agency (EPA) sponsored a research program on the Coaltek pipeline charging/preheat system at a steel plant in Pennsylvania. The test program was formulated by York Research Corporation (YRC) and directed toward inlet/outlet emission characterization around the venturi scrubber. Particular emphasis was to be placed upon the specific polycyclic organic materials (POMs) listed in Table 1.

SAMPLING METHODOLOGY

The test program was conducted during the months of July and August, 1978. Velocity, temperature, gas analysis and other parameters required for particulate and polycyclic organic materials (POM) sampling were recorded with isokinetic sampling maintained as specified by the following E.P.A. Methods:

- Method #1 - Sampling and velocity traverses for stationary sources
- Method #2 - Determination of stack gas velocity and volumetric flow rate (type S pitot tube)
- Method #3 - Gas analysis for CO_2, O_2 and dry molecular weight using an Orsat unit
- Method #4 - Determination of moisture content in stack gas, derived from actual sampling train

- Method #5 - Determination of particulate in the inlet and outlet to the coal preheater scrubber.

In addition to the above methods, extensive sampling was performed for POM determination using a POM sampling train with an Arthur D. Little XAD-2 adsorber.

Particulate Train

The particulate sampling apparatus consisted of a probe, cyclone bypass, filter, four impingers, dry gas meter, vacuum pump and flow meter (see Figure 2). The probe was 5 feet in length and glass lined. The stainless steel button-hook type probe tip was connected by a stainless steel coupling with Teflon packing to the probe. The probe consisted of a 5/8 inch outside diameter tube with a ground balljoint on one end. The probe was logarithmically wound from the entrance end with 26-gauge nickel-chromium wire. During sampling, the wire was connected to a variable transformer to maintain a gas temperature of 250°F in the probe. The wire wound tube was wrapped with fiberglass tape and encased in a 1-inch-OD stainless steel casing for protection. The nozzle was attached to the end of the probe casing. The probe was connected to a cyclone bypass and a very coarse fritted glass filter holder containing a tared glass fiber filter. The filter was contained in an electrically heated enclosed box thermostatically maintained at a temperature of 250°F to prevent condensation. Attached to the heated box was an ice bath containing four Greenburg-Smith design impingers connected in series with glass balljoints. The first impinger was modified by replacing the tip with a ½ inch ID glass tube extending to 0.5 inches from the bottom of the flask, and, with the second impinger, filled with 100 milliliters of distilled water. The third impinger was left dry. The fourth was modified as the first and charged with silica gel.

The effluent stream from the fourth impinger flowed through a check valve, flexible rubber vacuum tubing, vacuum gauge, a needle valve, a leakless vacuum pump (rated at 4 cubic feet per minute at 0 inches of mercury gauge pressure and 0 cubic feet per minute at 26 inches of mercury gauge pressure) connected in parallel with a bypass valve, and a dry gas meter rated at 0.1 cubic foot per revolution. A calibrated orifice completed the train and was used to measure instantaneous flow rates. The dual manometer across the calibrated orifice was an inclined-vertical type graduated in hundreths of an inch of water from 0 to 0.1 inch and in tenths from 1 to 10 inches.

POM Sampling Train

The POM sampling train, as shown in Figure 3, consisted of a Method 5 train with an adsorbent sampler located downstream of the filter and condenser and upstream of the impingers. Utilizing this arrangement, POM emissions could be determined by analysis of the probe wash, filter catch, condensate, and adsorbent sampler catch. The impingers were only used to cool and dry the stack gases before they entered the dry gas meter.

The POM train used in the field consisted of a heated glass-lined probe with a stainless steel nozzle at the probe head, a heated filter assembly, one Greenburg-Smith type condenser impinger, the adsorbent sampler and four additional impingers.

In order to insure adequate POM collection efficiency in the adsorbent sampler, the flue gas temperature had to be kept as low as possible without condensing large quantities of water vapor. For this reason, a condenser (Greenburg-Smith impinger) was used between the filter and the adsorbent sampler. Connected to the impinger assembly was an umbilical, vacuum pump, dry gas meter and an orifice. All connections in the filter, adsorber and impinger assemblies were glass. Thermal control at the probe and the filter assembly was maintained in a heated mode at 325°F (versus 250°F when using the EPA Method 5 sampling train). Maintaining the probe and filter at the higher temperature prevented condensation and/or adsorption of SO_3 and POM (followed by the destructive reaction of SO_3 with POM) in these components. Thermocouple connections at the probe head, the inlet to the filter assembly, the inlet to the adsorber, the fourth impinger outlet and the inlet/outlet of the dry gas meter, allowed for monitoring sampled flue gas temperatures throughout the sampling train.

Once completely assembled, the sampling train was leak-checked to insure collection of a representative flue gas sample. To perform the leak-check, the vacuum pump was started and the nozzle orifice covered to insure an air-tight seal. After bringing the vacuum pressure up to 15 psi, the dry gas meter was checked for any air leaks. Once the required leak check was performed, the probe was inserted into the duct at the specific sampling point. Velocity and temperature measurements of the flue gas at the pitot head were recorded and a sampling rate determined for isokinetic sampling.

SAMPLE RECOVERY

Recovery procedures for particulate analysis were essentially those published in the Federal Register (Vol. 36, No. 247, December 23, 1971) for the front half (acetone wash), the filter and the back half (water).

Sample recovery from the POM sampling train for POM analysis involved washing of four separate portions of the sampling train:

1) probe and glassware up to the filter,
2) filter,
3) condensate,
4) adsorbent sampler.

The extract from each component was sealed and kept in darkness while awaiting analysis.

ANALYTICAL METHODOLOGY

Particulate emission results were analyzed and characterized as either chloroform soluble or non-chloroform soluble using the methodology outlined in Table (2).

Two sets of organic analyses were performed on the samples obtained from eleven tests utilizing the POM sampling train.

- Gas Chromatography/Mass Spectrometry (GC/MS) Analysis

  All stack samples and six water samples (Tests 1, 2 and 3, both inlet and outlet) were carried through the procedures in Figure 4. Total particulate loading (probe methylene chloride wash, front half acetone wash, back half filter and condenser acetone wash) was determined and analyses carried out for twenty-five organic species (POM).

- EPA Level 1 Organic Analysis

  Six samples (inlet and outlet air samples from Test No. 2, inlet and outlet water samples from Test No. 2, stack blank, and water blank) were carried through the EPA level 1 organic analysis illustrated in Figure 5.

The individual procedures used in the analyses are described briefly as follows:

A. Particulate Weights

The solids from the front half methylene chloride probe wash, acetone wash, and filters were dried in a desiccator at room temperature to constant weight.

B. Soxhlet Extraction

All Soxhlet extractions were carried out for a 24 hour period using high purity methylene chloride (Burdick and Jackson, distilled-in-glass). The XAD-2 resin samples were extracted with about 500 mL of methylene chloride and particulate samples were extracted with about 300 mL of methylene chloride.

C. Liquid Extraction

Water samples were extracted with methylene chloride in separatory funnels fitted with Teflon stopcocks. The pH of the aqueous sample was adjusted first to 2.0 with hydrochloric acid and subsequently to 12.0 with sodium hydroxide. Two extractions were done at each pH, using a sample/methylene chloride volume ratio of about 20/1.

D. Total Chromatographable Organics Analysis (TCO)

The quantity of the total organic material with boiling points in the range of 100-300°C was determined by gas chromatography using a flame ionization detector. The concentration of each sample was calculated from the ratio of the peak areas of the sample to that of the known standards.

E. Gravimetric Analysis (GRAV)

The amounts of organic material with boiling points higher than 300°C were determined by the gravimetric analysis method (GRAV); one or five mL samples were pipetted into precleaned, dried and weighed aluminum dishes, and were dried at room temperature in a desiccator to constant weight.

F. Liquid Chromatography (LC)

The methylene chloride extracts from each test were combined and concentrated to 10-25 mL using a Kuderna Danish apparatus. From each concentrated extract 0.5 - 8 mL aliquots were subjected to three consecutive solvent exchanges with cyclopentane. The resultant cyclopentane solutions were chromatographed on a silica gel column, collecting seven fractions by elution with solvent mixtures (pentante-methylene chloride-methanol) of increasing polarity. A portion of fractions 2, 3 and 4 were combined for GC/MS analysis.

G. Infrared Spectroscopy (IR)

The IR spectra of all samples as potassium bromide micro-pellets were obtained on a Perkin-Elmer 521 grating spectrometer.

H. Low Resolution Mass Spectroscopy

LRMS analysis was carried out on a Dupont 21-110B spectrometer. Sample sizes varied from 20 μL to 50 μL. Typically, a sample was run at 15 ev and 70 ev ionization potentials over a temperature range of 70-350°C.

I. Gas Chromatography/Mass Spectrometry (GC/MS) Analysis

The combined aromatic fractions from each extract were analyzed for 25 POM species by the GC/MS technique. An OV-17 glass capillary GC column and a Finnigan Model 4023 Mass Spectrometer/Data System were used throughout the entire analysis.

The detection limits for the coal preheater stack air samples ranged from 0.8 $\mu g/m^3$ to 18 $\mu g/m^3$ for species having a molecular weight (MW) less than 252 and from 6 $\mu g/m^3$ to 120 $\mu g/m^3$ for species having a MW greater than 252, depending on the volume of concentrated extract and the volume of air sampled. The detection limits for the water samples were: 1 µg/L for MW <252 species and 8 µg/L for MW >252 species.

TEST RESULTS

Particulate emission results are summarized in Table 3 with the process conditions indicated in Table 4. On the basis of one test, scrubber inlet total particulate (chloroform and non-chloroform soluble particulate in front and back half catches, not including silica gel) concentration was 3.94 gr/DSCF (3.44 lb/ton coal). Outlet conentrations ranged from 0.416 gr/DSCF - 0.715 gr/DSCF (0.424 - 0.752 lb/ton coal) with the scrubber operating at 20 in. W.C. pressure drop and a liquid-to-gas ratio of approximately 8 gallons per 1000 ACFM.

Selected POM emission results with the specific scrubber water flow arrangement at the plant are summarized in Tables 5 and 6 with the process conditions indicated in Table 7.

Scrubber removal efficiency for selected POM species varied over a wide range (see Table 8) and was not particularly selective for the high molecular weight species. Table 9 indicates that, in general, POM emissions increase with increasing coal feed rate. Over the preheater outlet temperature range existing during the test program (500-550°F) no correlation between POM emission rate and preheater outlet temperature was identified.

Table 10 summarizes POM emission factor variability for selected individual species in light of the appropriate NAS carcinogenicity level. Tables 11, 12 and 13 indicate scrubber inlet/outlet particulate loadings from the POM train, scrubber inlet particulate loading by train component and scrubber outlet particulate loading by train component, respectively. Scrubber liquor inlet/outlet concentrations from selected POM species are presented in Table 14.

Among the compounds analyzed, the most abundant species found in all samples were naphthalene, anthracene, and phenanthrene. Lesser amounts of fluorene, pyrene, fluoranthene, benzofluoranthene, benzanthracene, chrysene, and benzopyrenes were also found in the air samples. Only the low molecular weight species such as naphthalene and anthracene were found in the water samples, with concentrations below the PPM level.

Although the analysis has been restricted to a narrow specific list of POM species, the GC/MS data system also made it possible to estimate the relative weight of selected POMs compared to the total aromatic fraction of the extracted sample. Original mass spectral data were acquired over a mass scan range of MW 125-310. Integration of this entire mass range provided a measure of the total aromatic content. It was then possible to extract the abundance of only those species with 3 or more rings (MW>178) from this total as a measure of total POM. Finally, a summation of the selected mass POM profiles (178, 202, 228, etc.) gives a measure of total selected POM.

For those samples investigated, the specific POMs of interest represented 3-10% of the sample, with the outlet sample having reduced amounts of the lighter species (i.e., 3-ring and higher-POMs represent ∿ 50% of the inlet samples compared to ∿ 90% of the outlet samples).

The percentage of the aromatic fraction of each sample represented by the specific POMs analyzed by GC/MS can also be estimated from the gravimetric analysis data. Table 15 shows that these values range from 3 to 14% for all the stack samples and less than 1% for the water samples from Test 3. Since the aromatic fraction represents about half of the total extract for most of these stack samples (Table 16), the specific POMs analyzed by GC/MS represent 2-7% of the total sample.

The precision of the POM data reported can be estimated from the scatter in the calibration curves and from results of other on going programs at Arthur D. Little, Inc. In studies whose scope has allowed for extensive quality control analysis of replicate and spiked samples, Arthur D. Little, Inc. has found that intralaboratory precision of ±15% relative standard deviation is regularly attainable by the GC/MS procedures described here. In interlaboratory comparisons, relative standard deviations of ±30% have been commonly observed. This 30% value probably represents an upper limit on the precision of the POM data in this report. The accuracy of the data is somewhat more difficult to estimate because recoveries of POMs from samples can be matrix dependent and because the sample extracts were stored (dark, refrigerated) for some time prior to analysis. In another Arthur D. Little, Inc. program, however, recoveries of POMs from water were generally found to be better than 75%.

DISCUSSION

One basis for evaluating the coal preheater emissions is to compare the concentrations of the various POM species found in the effluent stream to previously specified "levels of concern". The appropriate level of concern might be an NSPS or other emission guideline for some species but such values have not presently been defined for POMs. A set of Multimedia Environmental Goals (MEG's) for a wide range of chemical pollutants, including POM's, have been developed by and for EPA-IERL to provide consistent criteria for evaluating and comparing a variety of emission types. The coal preheater POM emission levels can be compared to the DMEG (Discharge MEG) values for those species to obtain a numerical discharge severity (DS) rating (3). The DMEG values for the POMs of interest are presented in Table 17. The ratio of estimated preheater emission levels to DMEG values are summarized in Tables 18, 19 and 20. In cases where two or more compounds of the same MW are not resolved in the GC/MS analysis, the assumption is made for the worst case, i.e., assuming all of the concentration is due to the species having the lowest DMEG value. For example, to get the discharge severity for benz(a) anthracene/benz(c) phenanthrene, the concentration found is divided by the DMEG of benz(a) anthracene (45 $\mu g/m^3$ in the air). Data thus obtained show that in most of the air samples the following POMs' exceed the DMEG level: phenanthrene, benz(a) anthracene, and 3-methylcholanthrene when present. These are all species for which the DMEG levels of concern are less than 50 $\mu g/m^3$ (ppb) in air. None of the POM species found in the water samples exceed their DMEG values for that medium.

The Level 1 Organic Analysis results for the two stack samples and two water samples are presented in Table 21. The concentration of each category was estimated using the method described in the EPA Level 1 procedure manual. Aliphatic hydrocarbons, fused aromatics, phenols, and esters were found to be the major components for both inlet and outlet stack samples. Aliphatic hydrocarbons, carbazoles, and phenols were found in the water samples.

RECOMMENDATIONS

The initial results generated from this research project suggest further study of:

1. The effect on particulate and POM emissions at varying scrubber liquid-to-gas ratios.
2. The effect on particulate and POM emissions at varying scrubber pressure drops.
3. The effect of scrubber recycle water quality on particulate and POM emissions.
4. The effect of different coal mixes (and sizing) on POM and particulate emissions.
5. The effect of other gas cleaning systems on POM emissions.

REFERENCES

(1) "Particulate Polycyclic Organics Material" Committee on Biologic Effects of Atmospheric Pollutants, Division of Medical Sciences, National Research Council, National Academy of Sciences, Washington, D.C., 1972

(2) Cleland, J.G., and G.L. Kingsbury, "Multimedia Environmental Goals for Environmental Assessment," Volumes 1 and 2, EPA-600/7-77-136a and b.

(3) Schalit, L.M., and K.J. Wolfe, "SAM/IA: A Rapid Screening Method for Environmental Assessment of Fossil Fuel Energy Process Effluents," Aerotherm Report TR-76-50, August 1977, EPA Contract 68-02-2160, T.D. No. 4.

(4) Rudolph, J.L., and Rechsteiner, C.E. "Analysis of Samples from Coal Preheater Effluent", A.D.L. report to York Research Corporation, ADL-C-82450, May 1979.

TABLE 1
POLYCYCLIC ORGANIC MATERIAL INVESTIGATED IN COAL PREHEATER SYSTEM EMISSION TEST PROGRAM

Species	MW	Carcinogenicity Rating*
Naphthalene	128	-
Fluorene	166	-
Anthracene/Phenanthrene	178	-
Fluoranthene	202	-
Pyrene	202	-
Benz(a)anthracene/(c)phenanthrene	228	+
Chrysene/Triphenylene	228	±
Benzo (b or k) fluoranthene	252	++
Benzo (j) fluoranthene	252	++
Benzo (e) pyrene	252	-
Benzo (a) pyrene	252	+++
Cholanthrene	254	++
Dimethyl benzanthracene isomers** (7,12-dimethyl benz(a)anthracene)	256	++++
Dibenzo (c,g) carbazole	267	+++
3-Methylcholanthrene	268	++++
Indeno (1,2,3-cd) pyrene	276	+
Benzo (ghi)perylene	276	-
Dibenz (ah or aj) anthracenes	278	+++
Dibenzacridines	279	++
Coronene	300	-
Dibenzo (a,h) pyrene	302	+++
Dibenzo (a,i) pyrene	302	+++

*Carcinogenicity Code(1)

-not carcinogenic

±uncertain or weak carcinogenic

+carcinogenic

++,+++,strongly carcinogenic
++++

**Includes dimethyl- and ethyl-chrysenes, benzophenanthrenes, and benzanthracenes.

TABLE 2A

EPA-5 SAMPLING TRAIN ANALYTICAL METHODOLOGY FOR EVALUATION OF CHLOROFORM-SOLUBLE AND NON-CHLOROFORM SOLUBLE PARTICULATE

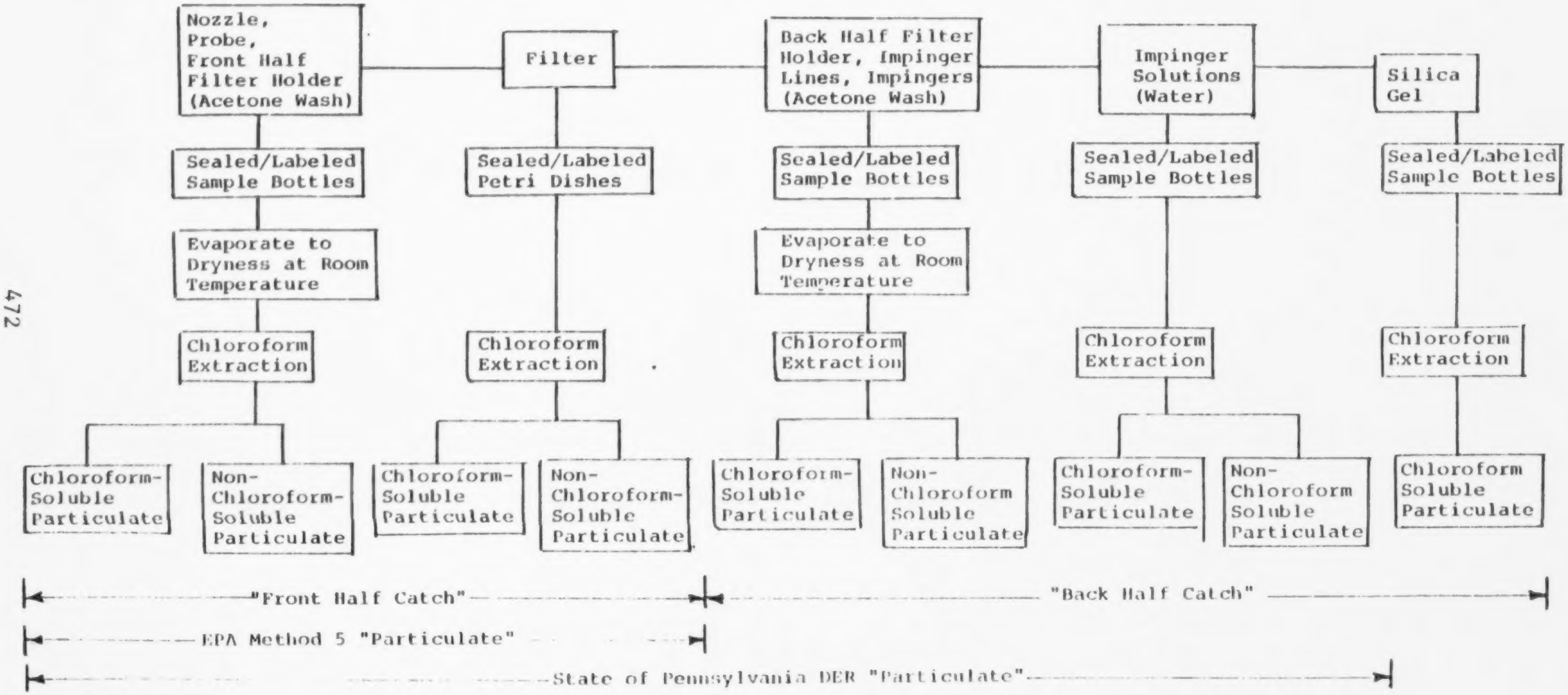
Nozzle, Probe, Front Half Filter Holder (Acetone Wash)
Filter
Back Half Filter Holder, Impinger Lines, Impingers (Acetone Wash)
Impinger Solutions (Water)
Silica Gel
Sealed/Labeled Sample Bottles
Sealed/Labeled Petri Dishes
Sealed/Labeled Sample Bottles
Sealed/Labeled Sample Bottles
Sealed/Labeled Sample Bottles
Evaporate to Dryness at Room Temperature
Evaporate to Dryness at Room Temperature
Chloroform Extraction
Chloroform Extraction
Chloroform Extraction
Chloroform Extraction
Chloroform Extraction
Chloroform-Soluble Particulate
Non-Chloroform-Soluble Particulate
Chloroform-Soluble Particulate
Non-Chloroform-Soluble Particulate
Chloroform-Soluble Particulate
Non-Chloroform Soluble Particulate
Chloroform-Soluble Particulate
Non-Chloroform Soluble Particulate
Chloroform Soluble Particulate
"Front Half Catch"
"Back Half Catch"
EPA Method 5 "Particulate"
State of Pennsylvania DER "Particulate"

TABLE 2B

POM SAMPLING TRAIN PARTICULATE ANALYSIS METHODOLOGY

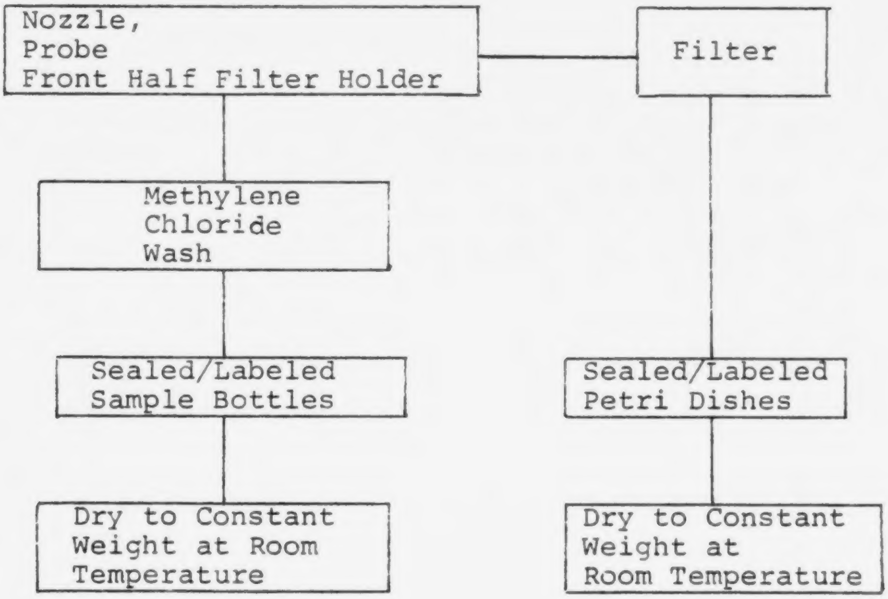
Nozzle,
Probe
Front Half Filter Holder
Filter
Methylene Chloride Wash
Sealed/Labeled Sample Bottles
Sealed/Labeled Petri Dishes
Dry to Constant Weight at Room Temperature
Dry to Constant Weight at Room Temperature

TABLE 3
CHLOROFORM SOLUBLE AND NON-CHLOROFORM SOLUBLE PARTICULATE EMISSION RATES

A. NON-CHLOFORORM SOLUBLE PARTICULATE EMISSIONS

		Particulate Emission Rate								
		Nozzle, Probe, Front Half Filter Holder			Filter			Back half filter holder Impinger lines, Impingers, Impinger Solutions		
Test No.	Scrubber Location	gr/DSCF	lb/ton	% Wt	gr/DSCF	lb/ton	% Wt	gr/DSCF	lb/ton	% Wt
1	Outlet	0.0396	0.0396	14.2	0.100	0.1025	36.4	0.136	0.1385	49.4
2	Inlet	0.403	0.352	11.2	2.956	2.581	82.0	0.246	0.215	6.8
	Outlet	0.026	0.018	7.2	0.25	0.178	69.4	0.084	0.06	23.4
3	Outlet	0.033	0.034	13.1	0.171	0.18	68.1	0.047	0.05	18.8

B. CHLOROFORM SOLUBLE PARTICULATE EMISSIONS

Test No.	Scrubber Location	gr/DSCF	lb/ton	% Wt	gr/DSCF	lb/ton	% Wt	gr/DSCF	lb/ton	% Wt
1	Outlet	0.00437	0.00446	1.3	0.0437	0.0446	12.5	0.0931	0.0951	26.7
2	Inlet	0.0408	0.0356	9.2	0.1822	0.159	41.0	0.1165	0.102	26.2
	Outlet	0.00327	0.00233	1.1	0.1757	0.125	58.2	0.0862	0.0614	28.6
3	Outlet	0.0011	0.0012	0.2	0.0616	0.065	11.8	0.4014	0.4216	76.9

A. NON-CHLOFORORM SOLUBLE PARTICULATE EMISSIONS

		Total		
Test No.	Scrubber Location	gr/DSCF	lb/ton	% Wt
1	Outlet	0.275	0.2806	100.0
2	Inlet	3.605	3.148	100.0
	Outlet	0.36	0.256	100.0
3	Outlet	0.251	0.264	100.0

B. CHLOROFORM SOLUBLE PARTICULATE EMISSIONS

		Silica Gel			Total		
		gr/DSCF	lb/ton	% Wt	gr/DSCF	lb/ton	% Wt
1	Outlet	0.2078	0.2122	59.5	0.349	0.356	100.00
2	Inlet	0.1047	0.0914	23.6	0.4442	0.388	100.00
	Outlet	0.0365	0.026	12.1	0.3017	0.215	100.00
3	Outlet	0.0581	0.061	11.1	0.5222	0.549	100.00

TABLE 4

COAL PREHEATER PROCESS DATA DURING PARTICULATE EMISSION RATE EVALUATION

Test No.	Coal Feed Rate (tph)	Preheater Outlet Temp. (^{o}F)	Scrubber Pressure Drop (in W.C.)	Scrubber Flowrate ACFM	Scrubber Flowrate DSCFM	Moisture (%)
1-outlet	84	532	20	26,823	10,011	53.2
2-inlet	105	520	20	43,186	10,700	53.5
2-outlet	105	520	20	20,791	8,728	52.0
3-outlet	90	520	20	32,192	11,030	58.0

TABLE 5

POM EMISSION FACTORS, LB/TON OF COAL

Test No.	Location	Naphthalene	Fluorene	Anthracene Phenanthrene	Fluoranthene	Pyrene	Benz(a)anthracene/ (c)phenanthrene	Chrysene/ Triphenylene	Benzo (b or k) Fluoranthene
1	Inlet	0.0012	0.00031	0.0022	0.00021	0.00022	0.00015	0.00026	0.00092
(60/530)	Outlet	0.0063	0.00058	0.0023	0.00016	0.00017	0.00005	0.00008	0.00003
2	Inlet	0.0062	0.0007	0.0039	0.00036	0.00032	0.00024	0.00048	0.00026
(90/520)	Outlet*	0.0091	0.00049	0.002	0.00018	0.0001			
3	Inlet	0.013	0.0018	0.0071	0.00052	0.00055	0.00038	0.00083	0.00052
(92/520)	Outlet	0.0085	0.00039	0.0015	0.0001	0.00011	0.00009	0.00029	
4 (120/500)	Outlet	0.016	0.0013	0.0032	0.00034	0.00031	0.00017	0.00034	0.00016
5 (119.5/550)	Outlet	0.0031	0.0018	0.009	0.00077	0.00067	0.00054	0.001	0.0005
6 (119/550)	Outlet	0.0053	0.0007	0.0033	0.00033	0.00037	0.00026	0.0007	0.0004
7 (90/550)	Outlet	0.0074	0.0019	0.0064	0.00033	0.00037	0.00037	0.00074	0.00055
8	Inlet	0.049	0.0056	0.018	0.0025	0.0022	0.0014	0.0022	0.0015
(120/520)	Outlet	0.012	0.0016	0.006	0.00068	0.0006	0.00044	0.00068	0.00064
10	Inlet	0.0096	0.0013	0.0091	0.00064	0.00064	0.0004	0.0009	0.00038
(90/520)	Outlet	0.008	0.0013	0.003	0.00015	0.00016	0.00007	0.00016	0.00009
11	Inlet	0.0047	0.0006	0.0031	0.00029	0.00025	0.00013	0.00031	0.00011
(90/500)	Outlet	0.0042	0.001	0.0036	0.00027	0.00025	0.00014	0.00028	0.00013

* Not Simultaneous

TABLE 6

POM EMISSION FACTORS
(lb/ton of Coal)

Test No.	Location	Benzo(j) Fluoranthene	Benzo(e) Pyrene	Benzo(a) Pyrene	Cholanthrene	Dimethyl Benzanthracene Isomers	Dibenzo (c,g) Carbazole	3- Methyl-Cholanthrene	Indeno (1,2,3-cd Pyrene	Benzo (ghi) Perylene	Dibenz (ah or aj) Anthracenes
1 (60/530)	Inlet		0.00016	0.00011		0.00035		0.00011	0.00006	0.00006	0.00006
	Outlet		0.00004	0.00003		0.00005					
2 (90/520)	Inlet		0.00022	0.00009		0.00061		0.00002	0.00001	0.00002	
	Outlet*		0.00008	0.00005							
3 (92/520)	Inlet		0.00044	0.00027		0.00091			0.00003	0.0001	
	Outlet		0.00004								
4 (120/520)	Outlet		0.00015	0.00006		0.00091					
5 (119.5/550)	Outlet		0.0002			0.0012					
6 (119/550)	Outlet		0.00036	0.00015		0.0012				0.00004	
7 (90/550)	Outlet	0.00003	0.00044	0.00023		0.00084		0.00006		0.00007	
8 (120/520)	Inlet	0.00017	0.0011	0.00067		0.0019			0.00007	0.00023	
	Outlet	0.00004	0.00035	0.00025		0.0015		0.00007	0.00004	0.00007	0.00003
10 (90/520)	Inlet	0.00002	0.00034	0.00013		0.00091			0.00003		
	Outlet	0.00001	0.00002			0.00014					
11 (90/500)	Inlet		0.00009	0.00003		0.00025			0.00001		
	Outlet	0.000008	0.00011	0.00005		0.00034			0.00002		

* Not Simultaneous

TABLE 7

COAL PREHEATER PROCESS DATA DURING POM EMISSION RATE EVALUATION

Test No.	Scrubber Location	Coal Feed Rate (tph)	Preheater Outlet Temp. (^{O}F)	Scrubber Pressure Drop (in W.C.)	Scrubber Flowrate		Moistu
					ACFM	DSCFM	(%)
1	Inlet	60	530	20	30,330	9,864	40.6
	Outlet	60	530	20	18,921	7,096	53.2
2	Inlet	90	520	20	41,649	14,693	36.4
	Outlet	90	520	20	32,230	16,826	34.5
3	Inlet	92	520	20	33,984	9,726	49.6
	Outlet	92	520	20	28,394	14,213	34.5
4	Inlet	120	500	20	45,348	12,239	53.7
	Outlet	120	500	20	30,431	12,088	51.9
5	Inlet	119.5	550	20	57,046	17,225	45.8
	Outlet	119.5	550	20	35,461	14,352	50.4
6	Inlet	119	550	20	58,907	17,378	44.4
	Outlet	119	550	20	35,304	13,032	53.0
7	Inlet	90	550	20	33,030	9,241	46.6
	Outlet	90	550	20	32,584	11,905	53.5
8	Inlet	120	520	20	54,431	16,409	44.3
	Outlet	120	520	20	34,809	12,755	53.0
9	Outlet	32	500	20	19,012	6,414	56.7
10	Inlet	90	520	20	43,779	12,815	46.6
	Outlet	90	520	20	22,610	8,330	53.0
11	Inlet	90	500	20	24,553	6,290	53.9
	Outlet	90	500	20	22,376	9,213	53.0

Note: Test No.2 inlet/outlet not simultaneous.

Test No.4 inlet, Test No.5 inlet, Test No.6 inlet, Test No.7 inlet and Test No.9 outlet sampling above acceptable isokinetic range (due to moisture variance)

TABLE 8

POM SCRUBBER EFFICIENCY ANALYSIS

Test No.	Process Data tph/°F	Emission Factor (Constant Scrubber ΔP) Inlet (lb/ton of coal)	Outlet (lb/ton of coal)	Efficiency %
1	60/530	0.0165	0.0097	41.2
2	90/520	0.0134	0.0028	79.1
3	92/520	0.0265	0.0110	58.5
4	120/500	0.0552	0.0232	58.0
6	119/550	0.0392	0.0131	66.6
8	120/520	0.0867	0.0253	70.8
10	90/520	0.0244	0.0130	46.7

TABLE 9

POM EMISSION RATE AS A FUNCTION OF COAL FEED RATE

Coal Feed Rate (tph)	Emission Factor (lb/ton of coal) Inlet	Outlet
60	0.0165	0.0097
90	0.0244	0.0130
90	0.0134	0.0028
92	0.0265	0.0110
119	0.0392	0.0131
120	0.0552	0.0232
120	0.0867	0.0253

TABLE 10

POM EMISSION FACTOR VARIABILITY

Species	Emission Factor Range* (lb/ton coal feed)			Carcinogenicity$^{(}$
Naphthalene	0.0017	-	0.039	-
Fluorene	0.00016	-	0.0044	-
Anthracene/Phenanthrene	0.00062	-	0.016	-
Fluoranthene	0.00004	-	0.0007	-
Pyrene	0.00004	-	0.0007	-
Benz(a)anthracene/(c) Phenanthrene	0.00003	-	0.0005	+
Chrysene/Triphenylene	0.00006	-	0.001	±
Benzo (b or k) fluoranthene	0.00003	-	0.0006	++
Benzo(j)fluoranthene	0.00001	-	0.00004	++
Benzo(e)pyrene	0.00002	-	0.00044	-
Benzo(a)pyrene	0.00001	-	0.00025	+++
Cholanthrene	----		-----	++
Dimethyl benzanthracene isomers (7,12-dimethyl benz(a)anthracene)	0.00005	-	0.0015	++++
Dibenzo (c,g) carbazole	----	-	----	+++
3-Methylcholanthrene	0.00005	-	0.00006	++++
Indeno (1,2,3-cd) pyrene	0.00002	-	0.00004	+
Benzo(ghi)perylene	0.00001	-	0.00007	-
Dibenz(ah or ah)anthracenes	0.00003	-		+++
Dibenzacridines	-----	-	----	++
Coronene	----	-	----	-
Dibenzo(a,h)pyrene	----	-	----	+++
Dibenzo(a,i)pyrene	----	-	----	+++

*Venturi Scrubber outlet (20 in W.C. pressure drop, L/G=8), 90-120 tph coal feed rate, 500-550^{O}F preheater outlet temperature range.

TABLE 11

SCRUBBER PARTICULATE REMOVAL EFFICIENCY DATA FROM POM TRAIN

Test No.	Coal Feed (tph) / Preheater Outlet Temperature ($^{\circ}F$)	Inlet (gr/DSCF)	Outlet (gr/DSCF)	Scrubber Efficiency%
1	60/530	5.623	0.176	96.9
2	90/520	4.556	0.041	99.1
3	92/520	1.889	0.155	91.8
4	120/500	----	0.330	----
5	119.5/550	----	0.743	----
6	119/550	----	0.729	----
7	90/550	----	0.477	----
8	120/520	5.708	0.557	90.2
10	90/520	9.172	0.165	98.2
11	90/500	6.544	0.549	91.6

TABLE 12

SCRUBBER INLET PARTICULATE LOADING DATA FROM POM TRAIN

Test No.	Nozzle, Probe and Front Half Filter Holder Wash (Methylene Chloride), gr/DSCF (%wt)	Filter gr/DSCF (%wt)
1	1.353 (24.1)	4.27 (75.9)
2	1.306 (28.7)	3.25 (71.3)
3*	1.609 (85.2)	0.28 (14.8)
8	1.478 (25.9)	4.23 (74.1)
10	3.632 (39.6)	5.54 (60.4)
11	2.01 (30.7)	4.534 (69.3)

* Data being re-evaluated.

TABLE 13

SCRUBBER OUTLET PARTICULATE LOADING DATA FROM POM TRAIN

Test No.	Nozzle, Probe, Front Half Filter Holder Wash (Methylene Chloride), gr/DSCF (%wt	Filter gr/DSCF (%wt)
1	0.047 (26.7)	0.129 (73.3)
2	0.026 (63.4)	0.015 (36.6)
3	0.016 (10.3)	0.139 (89.7)
4	0.009 (2.7)	0.321 (97.3)
5	0.02 (2.7)	0.723 (97.3)
6	0.022 (3.0)	0.707 (97.0)
7	0.028 (5.9)	0.449 (94.1)
8	0.02 (3.6)	0.537 (96.4)
10	0.031 (18.8)	0.134 (81.2)
11	0.031 (5.6)	0.518 (94.4)

TABLE 14
SCRUBBER WATER INLET-OUTLET ANALYSIS

	CONCENTRATION (mg/L)					
Component	Test No. 1		Test No. 2		Test No. 3	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Naphthalene	0.27	0.05	0.28	0.01	0.03	0.05
Fluorene	0.02	---	0.07	0.01	0.01	0.01
Anthracene/ Phenanthrene	0.06	0.04	0.17	0.02	0.16	0.04
Fluoranthene	0.01	---	0.01	---	0.02	---
Pyrene	0.02	---	0.02	---	0.02	0.01
Benz(a)anthracene/(c)phenanthrene	---	---	---	---	0.01	---
Chrysene Triphenylene	---	---	---	---	0.02	---
Benzo(e)pyrene	---	---	---	---	0.01	---
Dimethyl Benzanthracene isomers	---	---	---	---	0.02	---
Totals	0.38	0.09	0.55	0.04	0.30	0.11

TABLE 15

Analyses of Aromatic Fractions (mg/m^3)

Sample No.	GRAV*	POM**	% POM/GRAV
1, Inlet	394	27	6.9
1, Outlet	154	22	14
2, Inlet	359	22	6.1
2, Outlet	93	3.2	3.4
2B, Outlet	146	18	12
3, Inlet	1450	67	4.6
3, Outlet	323	19	5.9
4, Inlet	1230	150	12
4, Outlet	549	61	11
5, Inlet	977	69	7.1
5, Outlet	1410	104	7.4
6, Inlet	1610	72	4.5
6, Outlet	1190	32	2.7
7, Inlet	1310	53	4.1
7, Outlet	1130	40	3.5
8, Inlet	1370	170	12
8, Outlet	1040	64	6.1
9, Outlet	1961	81	4.1
10, Inlet	770	45	5.8
10, Outlet	371	38	10
11, Inlet	593	37	6.2
11, Outlet	269	27	10
H_2O, 3 Inlet	38	.3	.9
H_2O, 3 Outlet	22	.12	.5

* GRAV value for combined aromatic LC fractions (LC 2, 3, and 4).

** Sum of concentrations of specific POM determined by GC/MS.

TABLE 16

Gravimetric Analysis of Coal Preheater Samples

Sample No.	Aromatic Fractions* (mg/m^3)	Total** (mg/m^3)	Aromatic Total (%)
1, Inlet	394	668	59
1, Outlet	154	603	26
2A, Inlet	359	807	44
2A, Outlet	93	175	53
2B, Outlet	146	439	33
3, Inlet	1450	2580	56
3, Outlet	323	807	40
4, Inlet	1230	2680	46
4, Outlet	549	1520	36
5, Inlet	977	2080	47
5, Outlet	1410	2740	51
6, Inlet	1610	3610	45
6, Outlet	1190	2730	44
7, Inlet	1310	1950	67
7, Outlet	1130	2040	55
8, Inlet	1370	2960	46
8, Outlet	1040	2340	44
9, Outlet	196	843	23
10, Inlet	770	2140	36
10, Outlet	371	1130	33
11, Inlet	593	1290	46
11, Outlet	269	840	32
H_2O, 3 Inlet	38	59	64
H_2O, 3 Outlet	22	92	24

* GRAV value for combined aromatic LC fractions (LC 2, 3, and 4).

** GRAV value for total sample extract prior to LC separation.

TABLE 17

POM DMEG Values Based on Health Effects

Species	MW	Air, $\mu g/m^3$	Water, $\mu g/L$
Naphthalene	128	5×10^4	7.5×10^5
Fluorene	166	*	
Anthracene	178	5.6×10^4	8.4×10^5
Phenanthrene	178	1.6×10^3	2.4×10^4
Fluoranthene	202	9×10^4	1.4×10^6
Pyrene	202	2.3×10^5	3.5×10^6
Benz(a)anthracene	228	45	670
Benzo(c)phenanthrene	228	2.7×10^4	4.1×10^5
Chrysene	228	2.2×10^3	3.3×10^4
Triphenylene	228		
Benzo(b)fluoranthene	252	900	1.3×10^4
Benzo(k)fluoranthene	252	1.6×10^3	2.5×10^4
Benzo(j)fluoranthene	252	6.5×10^3	9.8×10^4
Benzo(e)pyrene	252	3×10^3	4.6×10^4
Benzo(a)pyrene	252	0.02	0.3
Cholanthrene	254		
12-Dimethyl benz(a)anthracene	256	0.26	3.9
Dibenzo(c,g)carbazole	267		
3-Methylcholanthrene	268	3.8	.56
Indeno(1,2,3-cd)pyrene	276	1.6×10^3	2.4×10^4
Benzo(ghi)perylene	276		
Dibenz(ah)anthracene	278	0.093	1.4
Dibenz(a,h)acridine	279	220	3.4×10^3
Dibenz(a,j)acridine	279	250	3.7×10^3
Coronene	300		
Dibenzo(a,h)pyrene	302	3.7×10^3	5.6×10^4
Dibenzo(a,i)pyrene	302	43	650

* All blanks are data not available

TABLE 18

DISCHARGE SEVERITY CALCULATED FOR POM IN COAL PREHEATER SAMPLES, OUTLET

Discharge Severity (DS)

Species	m/e	Test Number					
		1	2	3	4	5	6
Naphthalene	128	0.3	0.04	0.3	0.9	1	0.3
Fluorene	166	-	-	-	-	-	-
Anthracene/Phenanthrene	178	3^a	0.4^a	2^a	5^a	10^a	5^a
Fluoranthene	202	0.004	0.0005	0.002	0.01	0.02	0.009
Pyrene	202	0.002	0.0002	0.0008	0.004	0.006	0.004
Benz(a)anthracene/(c)phenanthrene	228	2^b	0.7^b	4^b	10^b	30^b	10^b
Chrysene/Triphenylene	228	0.1^c	0.04^c	0.3^c	0.5^c	1^c	0.9^c
Benzo(b or k)fluoranthene	252	0.08^d	0.03^d		0.5^d	1^d	1^d
Benzo(j)fluoranthene	252	**					
Benzo(e)pyrene	252	0.03	0.008	0.02	0.1	0.2	0.3
Benzo(a)pyrene	252	3000	500		9000		18500
Cholanthrene	254						
Dimethyl benzanthracene isomers*	256	500^e	300^e		9000^e	10000^e	10000^e
Dibenzo(c,g)carbazole	267						
3-Methylcholanthrene	268						
Indeno(1,2,3-cd)pyrene	276						
Benzo(ghi)perylene	276		-				-
Dibenz(ah or aj) anthracenes	278						
Dibenzacridines	279						
Coronene	300						
Dibenzo(a,h)pyrene	302						
Dibenzo(a,i)pyrene	302						

* Includes dimethyl- and ethyl-chrysenes, benzophenanthrenes, benzathracenes.

** All blanks are items below detection limit.

- DMEG values are not available.

a. Based on DMEG of Phenanthrene.

b. Based on DMEG of Benz(a)anthracene.

c. Based on DMEG of Chrysene.

d. Based on DMEG of Benzo(b) fluoranthrene.

e. Based on DMEG of 7,12-Dimethyl benz(a) anthracene.

TABLE 19

DISCHARGE SEVERITY CALCULATED FOR POM IN COAL PREHEATER SAMPLES, OUTLET

Discharge Severity (DS)

Species	m/e	Test Number					
		7	8	9	10	11	2B
Naphthalene	128	0.3	0.6	1	0.5	0.2	0.3
Fluorene	166	-	-	-	-	-	-
Anthracene/Phenanthrene	178	8^a	9^a	10^a	5^a	6^a	2^a
Fluoranthene	202	0.007	0.02	0.01	0.005	0.008	0.003
Pyrene	202	0.003	0.007	0.004	0.002	0.003	0.0006
Benz(a)anthracene/(c)phenanthrene	228	20^b	30^b	2^b	4^b	8^b	6^b
Chrysene/Triphenylene	228	0.8^c	0.9^c	0.1^c	0.3^c	0.4^c	0.2^c
Benzo(b or k)fluoranthene	252	1^d	2^d	0.05^d	0.3^d	0.4^d	
Benzo(j)fluoranthene	252	0.01	0.01		0.004	0.004	
Benzo(e)pyrene	252	0.3	0.3	0.03	0.02	0.09	0.04
Benzo(a)pyrene	252	20000	30000	1000		7000	4000
Cholanthrene	254						
Dimethyl benzanthracene isomers*	256	7000^e	10000^e		2000^e	3000^e	
Dibenzo(c,g)carbazole	267						
3-Methylcholanthrene	268	30	40				
Indeno(1,2,3-cd)pyrene	276		0.06				
Benzo(ghi)perylene	276	-	-			-	
Dibenz(ah or aj) anthracenes	278		800^f				
Dibenzacridines	279						
Coronene	300						
Dibenzo(a,h)pyrene	302						
Dibenzo(a,i)pyrene	302						

* Includes dimethyl- and ethyl-chrysenes, benzo phenanthrenes benzathracenes.

** All blanks are items below detection limit.

- DMEG values are not available.

a. Based on DMEG of Phenanthrene.

b. Based on DMEG of Benz(a)anthracene.

c. Based on DMEG of Chrysene.

d. Based on DMEG of Benzo(b)fluoranthene.

e. Based on DMEG of 7,12-Dimethyl benz(a) anthracene.

f. Based on DMEG of Dibenz(ah)anthracene.

TABLE 20

DISCHARGE SEVERITY CALCULATED FOR POM IN COAL PREHEATER SAMPLES, OUTLET

Discharge Severity

Species	m/e	Test Number		
		1, H_2O	2, H_2O	3, H_2O
Naphthalene	128	7×10^{-5}	2×10^{-5}	7×10^{-5}
Fluorene	166		-	-
Anthracene/Phenanthrene	178	2×10^{-3}	9×10^{-4}	2×10^{-3}
Fluoranthene	202			3×10^{-6}
Pyrene	202	1×10^{-6}		2×10^{-6}
Benz(a)anthracene/(c)phenanthrene	228			
Chrysene/Triphenylene	228			
Benzo(b or k)fluoranthene	252			
Benzo(j)fluoranthene	252			
Benzo(e)pyrene	252			
Benzo(a)pyrene	252			
Cholanthrene	254			
Dimethyl benzanthracene isomers*	256			
Dibenzo(c,g)carbazole	267			
3-Methylcholanthrene	268			
Indeno(1,2,3-cd)pyrene	276			
Benzo(ghi)perylene	276			
Dibenz(ah or aj) anthracenes	278			
Dibenzacridines	279			
Coronene	300			
Dibenzo(a,h)pyrene	302			
Dibenzo(a,i)pyrene	302			

* Includes dimethy- and ethyl-chrysenes, benzophenanthrenes, and benzanthracenes.

** All blanks are items below detection limit.

- DMEG values are not available.

Table 21

Total Organics for Stack and Water Samples

	Stack Samples (mg/Nm^3)		Water Samples (mg/L)	
Compound Categories	2A Inlet	2A Outlet	2 Inlet	2 Outlet
Aliphatic Hydrocarbons	190	74	69	54
Aromatic Hydrocarbons				28
Fused Aromatics, <MW 216	340	8	13	
Fused Aromatics, >MW 216	280	48	13	
Heterocyclic N Compounds	20	33	16	15
Aldehydes & Ketones			14	14
Alcohols, Phenols	120		14	15
Esters	150	31	1	48
Carboxylic Acids				3

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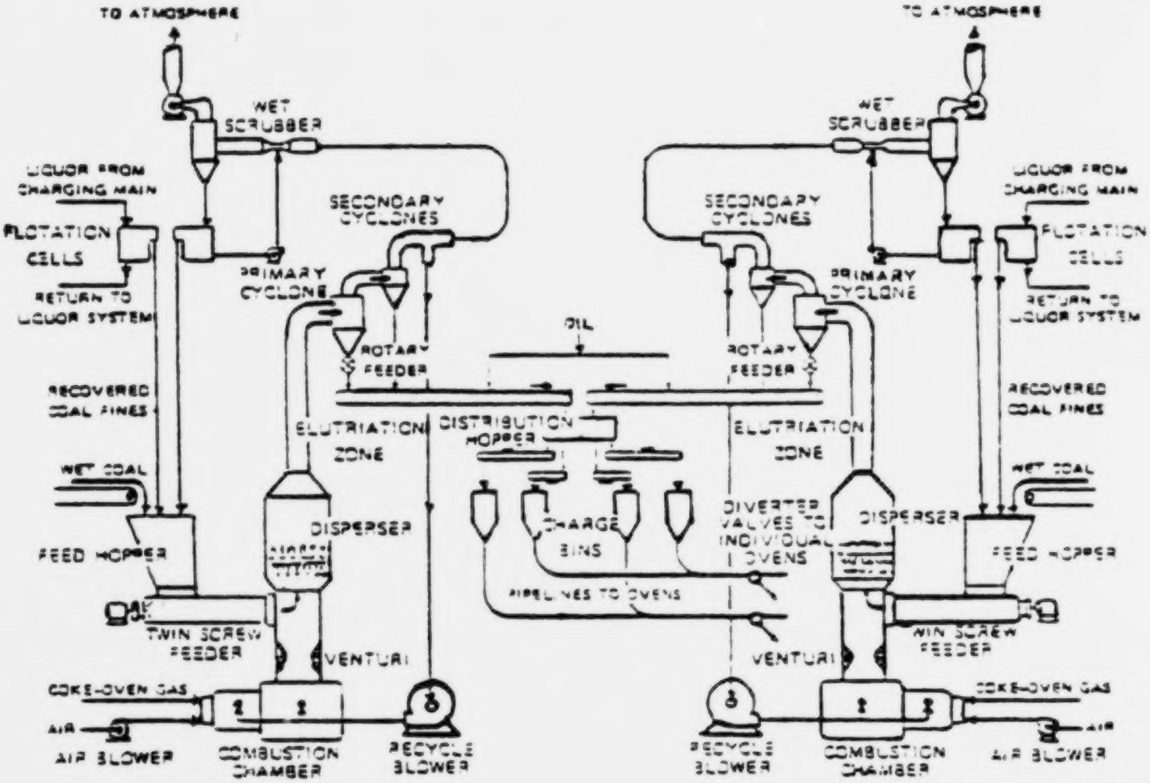

TO ATMOSPHERE
WET SCRUBBER
LIQUOR FROM CHARGING MAIN
FLOTATION CELLS
RETURN TO LIQUOR SYSTEM
SECONDARY CYCLONES
PRIMARY CYCLONE
ROTARY FEEDER
OIL
RECOVERED COAL FINES
ELUTRIATION ZONE
DISTRIBUTION HOPPER
WET COAL
DISPERSER
CHARGE BINS
DIVERTER VALVES TO INDIVIDUAL OVENS
FEED HOPPER
PIPELINES TO OVENS
TWIN SCREW FEEDER
VENTURI
COKE-OVEN GAS
AIR
AIR BLOWER
COMBUSTION CHAMBER
RECYCLE BLOWER
TO ATMOSPHERE
WET SCRUBBER
LIQUOR FROM CHARGING MAIN
FLOTATION CELLS
RETURN TO LIQUOR SYSTEM
SECONDARY CYCLONES
PRIMARY CYCLONE
ROTARY FEEDER
RECOVERED COAL FINES
ELUTRIATION ZONE
WET COAL
DISPERSER
FEED HOPPER
TWIN SCREW FEEDER
VENTURI
COKE-OVEN GAS
AIR
AIR BLOWER
COMBUSTION CHAMBER
RECYCLE BLOWER

Figure 1. Preheating System for the Coaltek Pipeline Charging Process for Coke Ovens.

FIGURE 2

PARTICULATE SAMPLING TRAIN
(Without Cyclone)

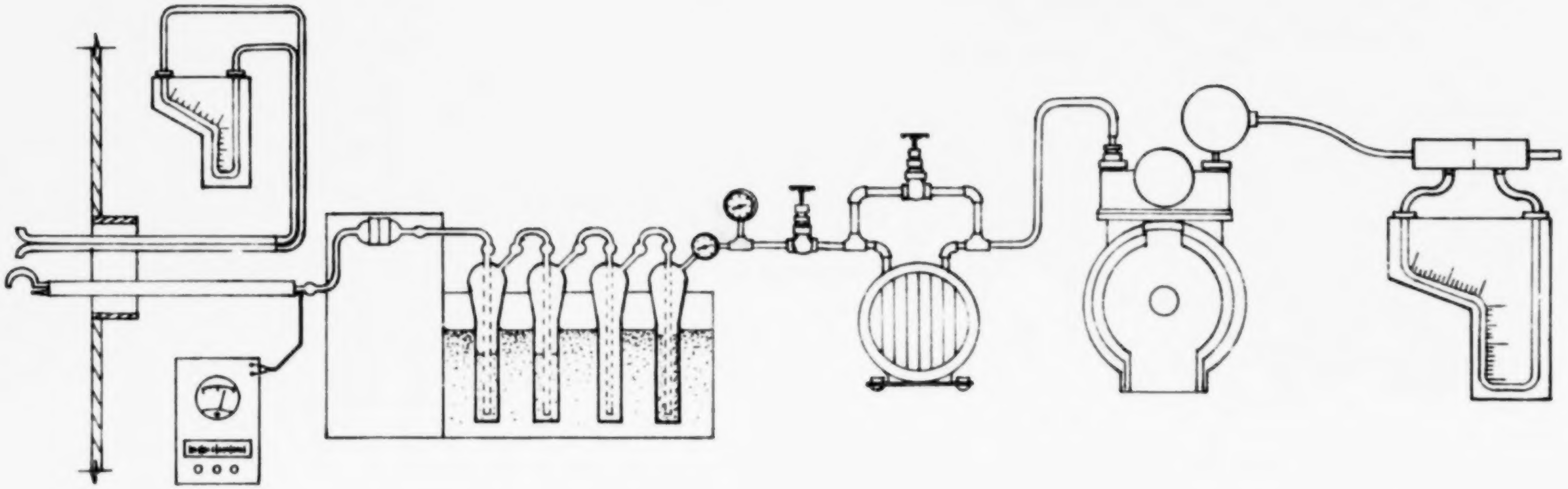
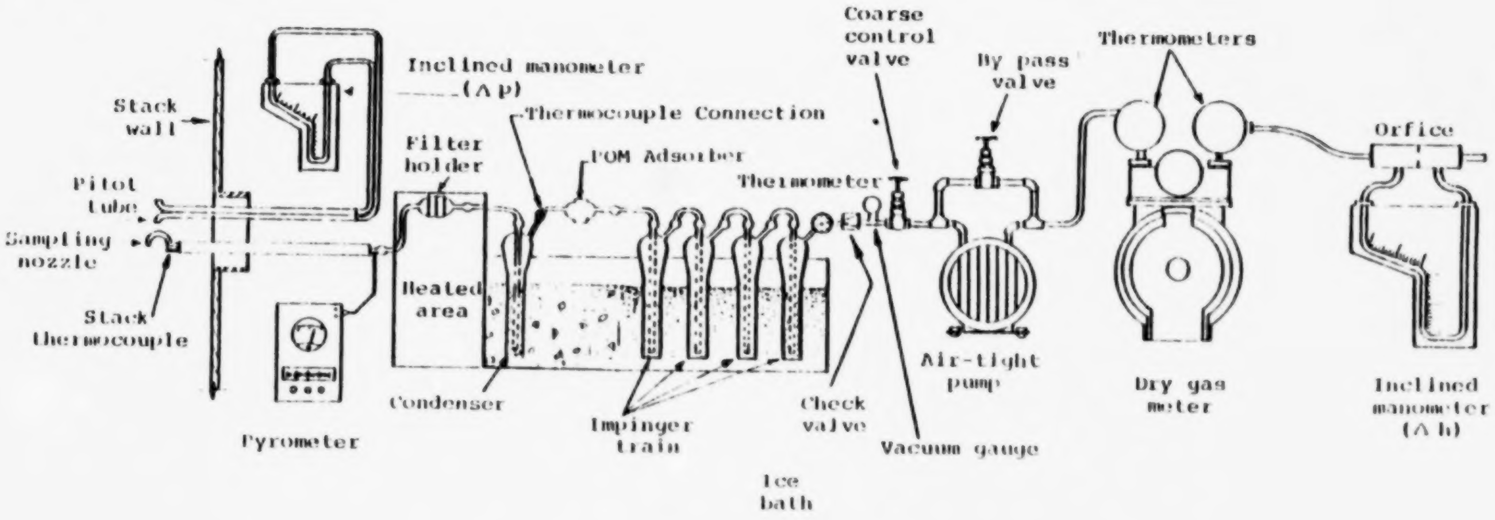


Figure 3

POM SAMPLING TRAIN


Stack wall
Pitot tube
Sampling nozzle
Stack thermocouple
Pyrometer
Inclined manometer (Δp)
Filter holder
Heated area
Thermocouple Connection
Condenser
POM Adsorber
Impinger train
Ice bath
Thermometer
Check valve
Vacuum gauge
Coarse control valve
By pass valve
Air-tight pump
Thermometers
Dry gas meter
Orfice
Inclined manometer (Δh)

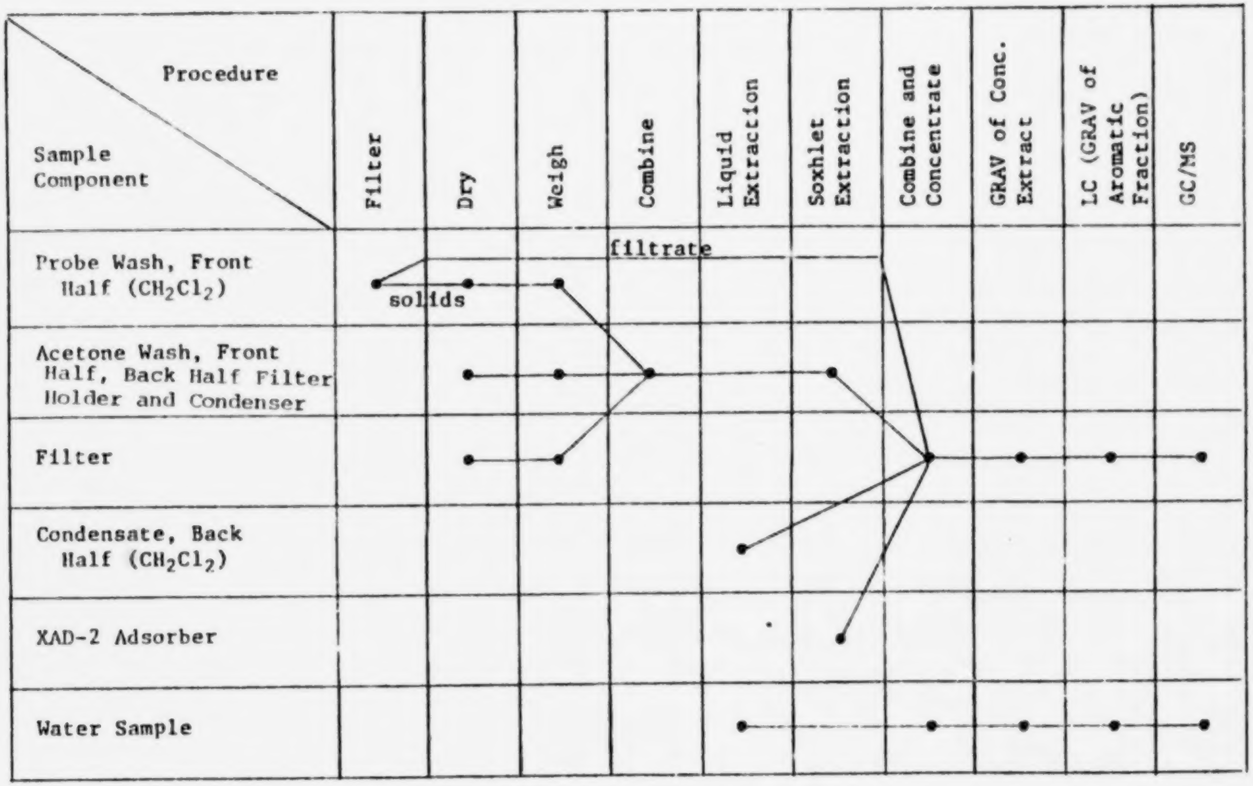

Procedure
Sample Component
Filter
Dry
Weigh
Combine
Liquid Extraction
Soxhlet Extraction
Combine and Concentrate
GRAV of Conc. Extract
LC (GRAV of Aromatic Fraction)
GC/MS
Probe Wash, Front Half (CH_2Cl_2)
filtrate
solids
Acetone Wash, Front Half, Back Half Filter Holder and Condenser
Filter
Condensate, Back Half (CH_2Cl_2)
XAD-2 Adsorber
Water Sample

Figure 4 GC/MS Analysis

Procedure Sample No.	Conc. Extract	TCO	GRAV	IR	LC	TCO (7 LC fractions)	GRAV (7 LC fractions)	IR (7 LC fractions)	LRMS (7 LC fractions)
2, Inlet	●	●	●	●	●	●	●	●	●
2, Outlet	●	●	●	●	●	●	●	●	●
H_2O, 2, Inlet	●	●	●	●	●	●	●	●	●
H_2O, 2, Outlet	●	●	●	●	●	●	●	●	●
Stack Blank	●	●	●	●	●	●	●	●	●
H_2O Blank	●	●	●	●	●	●	●	●	●

Figure 5 EPA Level 1 Organic Analysis

APPENDIX A

Attendees

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ATTENDEES

IRON AND STEEL POLLUTION
ABATEMENT TECHNOLOGY SYMPOSIUM
October 30, 31, and November 1, 1979
Pick-Congress Hotel Chicago, IL

Ackermann	Kurt J.	3426 E. 89th St.	Chicago	IL	60617	United States Steel Corp. - South Works
Akacem	Amed	161 E. 42nd St.	New York	NY	10017	Koch Engineering
Ali-Khan	M.	900 East Chicago Avenue	East Chicago	IN	46312	City of E. Chicago Air Quality Dept.
Allaman	G. L.	152 Floral Avenue	Murray Hill	NJ	07974	Wilputte Corporation
Allen	C. Clark	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Allen	John E.	P. O. Box 843	Lake Forest	IL	60045	J. E. Allen and Associates, Inc.
Alton	D. E.	35 E. Wacker Dr.	Chicago	IL	60601	Kaiser Engineers, Inc.
Amendola	Gary A.	25089 Center Ridge Road	Westlake	OH	44145	U.S. EPA, Region V Eastern Dist. Office
Anderson	Peter	Burlington Road	Bedford	MA	01730	GCA/Technology Division
Antoine	J. A.	BP 36	Maizieres-Les-Metz	France	57210	L. E. C. E. S.
Arent	David	6th and Walnut Streets	Philadelphia	PA	19106	U. S. EPA
Armour	F. K.	150 W. 137th Street	Chicago	IL	60627	Interlake, Inc.
Aust	Walter D.	3 Parkway Center, Suite 315	Pittsburgh	PA	15220	AMI International, Inc.
Aver	Franklin A.	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Balajee	Shank R.	3001 E. Columbus Drive	East Chicago	IN	46312	Inland Steel Company
Balla	Paul A.	1465 Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corp.
Ban	Tom	113 St. Clair	Cleveland	OH	44121	McDowell-Wellman Co.
Banister	Mark R.	2401 West 26th St.	Erie	PA	16506	Erie Testing Laboratories
Batta	Naresh	200 North 7th Street	Lebanon	PA	17042	Buell Envirotech Corporation
Bandy	Robert	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Beck	Lee	MD-13	Research Triangle Park	NC	27711	U.S. EPA, RTP
Benzer	W. C.	1000 16th Street, N. W.	Washington	DC	20036	American Iron and Steel Institute
Bergman	Kathleen	430 W. Randolph	Chicago	IL	60606	Rooks, Pitts, Fullagar & Poust
Berkebile	David G.	8th Street N. E., P. O. Box 700	Canton	OH	44701	Republic Steel Corporation
Bhargava	Pankaj	1800 FMC Drive	Itasca	IL	60143	FMC Corporation
Bhattacharyya	A.	P. O. Box A - South Park Station	Buffalo	NY	14220	Donner-Hanna Coke Joint Venture
Bhattacharyya	S.	10 West 35th Street	Chicago	IL	60616	IIT Research Institute
Billmyre	Richard D.	515 So. Harmon	Indianapolis	IN	46225	Crown Environmental Control Systems, Inc
Blair	Thomas R.	P. O. Box 9948	Austin	TX	78766	Radian Corp.
Blaszak	Thomas	465 Fullerton Avenue	Elmhurst	IL	60126	Pacific Environmental Services
Bloom	Bernard	401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Bodnaruk	B. J.	230 S. Dearborn, Air Enforcement	Chicago	IL	60604	U.S. EPA
Bores	Joseph A.	1910 Cochran Road	Pittsburgh	PA	15122	NUS Corporation
Bouffard	Ernest J.	One Penn Plaza	New York	NY	10001	Chemico Air Pollution Board
Boyer	Howard A.	Box 1013R	Morristown	NJ	07960	Allied Chemical Corp.
Branscome	Marvin	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Bridle	Trevor	P. O. Box 5050, Wastewater Tech. Ctr.	Burlington, Ontario	Canada	L7R 4A6	Environmental Protection Service
Broczkowski	Edmund	North Point Boulevard	Sparrows Point	MD	21219	Bethlehem Steel Corp.
Broman	Carl	Indiana Harbor Works	East Chicago	IN	46312	Jones & Laughlin Steel Corp.
Brown	Clifford M.	P. O. Box 6778 (519 R)	Cleveland	OH	44101	Republic Steel Corporation
Brown	H. M.	24100 Chagrin Blvd.	Cleveland	OH	44122	Loria Brothers & Co., Inc
Browne	William R.	135 Cumberland Road	Pittsburgh	PA	15237	Bischoff Environmental Systems
Buonicore	Anthony J.	One Research Drive	Stamford	CT	06906	York Research Corporation
Burchard	John K.	IERL, MD-60	Research Triangle Park	NC	27711	U.S. EPA, RTP
Cairns	D. F.	20th & State Street	Granite City	IL	62040	National Steel Corporation
Campbell	J. M.	P. O. Box 74, Lodgate Lane	Middlesbrough, Cleveland	England	TS8 9EG	British Steel Corp., Teesside Lab.
Capellini	Albert	P. O. Box 5200	Cherry Hill	NJ	08034	Stone & Webster Engineering Corporation
Case	Paula J.	2301 Adams	Granite City	IL	62040	Granite City Air Pollution Cont. Agcy.
Cashman	Peter L.	One Research Drive	Stamford	CT	06906	York Research Corporation
Centi	Thomas J.	1910 Cochran Road	Pittsburgh	PA	15220	NUS Corporation

Chabala	David M.	Universal-Cyclops Div., Mayer St.	Bridgeville	PA	15017	Cyclops Corporation
Chung	Neville K.	50 Staniford St.	Boston	MA	02114	Metcalf & Eddy, Inc.
Clark	William D.	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Clum	James A.	1509 University Avenue	Madison	WI	53706	University of Wisconsin - Madison
Cole	W. T.	100 King St., W.	Hamilton, Ontario	Canada	L8N 3T1	The Steel Co. of Canada, Ltd.
Costantino	Michael S.	628 West Parklane Towers	Dearborn	MI	48126	Ford Motor Co.
Cowherd	Chatten	425 Volker Boulevard	Kansas City	MO	64110	Midwest Research Institute
Cox	Terry E.	309 W. Washington	Chicago	IL	60606	State of Ill., Pollution Control Board
Coy	David W.	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Craig	A. B.	MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
Craig	Richard	26 Federal Plaza, Room 802	New York	NY	10007	U.S. EPA, Region II
Crawford	David	1567 Old Abers Creek Road	Monroeville	PA	15146	Materials Consultants and Laboratories
Current	Gene P.	Weirton Steel Division	Weirton	WV	26062	National Steel Corporation
Dahlgren, Jr.	Allan G.	Box 401	Beaver Falls	PA	15010	Babcock & Wilcox Co.
Dale	Larry	8678 Ridgefield Road	Crystal Lake	IL	60010	Baxter & Woodman, Inc.
Davison	James W.	One Research Drive	Stamford	CT	06906	York Research Corporation
Desai	Sudhir	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
deSante	Richard K.		Wilmington	DE	19898	E. I. du Pont de Nemours & Co., Inc.
Dick	Marshall	401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Dincher	Tom	800 E. Northwest Highway, Ste. 330	Palatine	IL	60067	Dincher Associates, Inc.
Draper	Glenn G.	1201 Elm Street	Dallas	TX	75270	U.S. EPA, Region VI
DuBroff	William	3001 E. Columbus Drive	East Chicago	IN	46312	Inland Steel Company
Dulaney	Edward L.	401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Duvall	L. A.	4017 Nanway Blvd.	Ravenna	OH	44266	Colerapa Industries, Inc.
Egan	Richard P.	P. O. Box 6428	Fort Myers	FL	33901	The Munters Corporation
Elphinstone	David D.	600 Grant St.	Pittsburgh	PA	15032	U.S. Steel Corporation
Erickson	Boyd C.	P. O. Box 510	Provo	UT	84601	U.S. Steel Corporation - Geneva Works
Erskine	George	1820 Dolley Madison Boulevard	McLean	VA	22102	The MITRE Corporation
Farnsworth	Douglas	EN-341, 401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Fosnacht	Donald R.	3001 E. Columbus Drive	East Chicago	IN	46312	Inland Steel Company
Franco	Nicholas B.	Homer Research Labs	Bethlehem	PA	18016	Bethlehem Steel Corp.
Friedman	Max	One Penn Plaza	New York	NY	10001	Chemico Air Pollution Control Co.
Fullerton	R. W.		Monroeville	PA	15146	U.S. Steel Corporation
Gage	Stephen J.	401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Garzella	Jack	11236 So. Torrence Ave.	Chicago	IL	60617	Interlake, Inc.
Geddis	Robert	345 Courtland St.	Atlanta	GA	30341	U.S. EPA
Geinopolos	Anthony	5103 W. Beloit Road	Milwaukee	WI	53214	Rexnord, Inc.
Goodfellow	Howard	21 St. Clair Avenue East	Toronto, Ontario	Canada	M4T 1L9	Hatch Associates, Ltd.
Goodman	Irvin G.	309 W. Washington	Chicago	IL	60606	State of Ill., Pollution Control Board
Goodwin	Don R.	OAQPS, MD-13	Research Triangle Park	NC	27711	U.S. EPA, RTP
Gorman	Edmond	EN-341, 401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Gravenstreter	James P.	600 Grant St.	Pittsburgh	PA	15230	U.S. Steel Corporation
Green	Lois	215 Fremont St., Enforcement Div.	San Francisco	CA	94105	U.S. EPA, Region IX
Greene	Kevin	59 E. Van Buren	Chicago	IL	60605	Citizens for a Better Environment
Greene	Robert A.	P. O. Box 226	Midland	PA	15059	Crucible, Inc.
Greenfield	Murray	Box 460	Hamilton, Ontario	Canada	L8N 3J5	Dominion Foundries & Steel Co.
Gronberg	Stephen	Burlington Road	Bedford	MA	01730	GCA/Technology Division
Hackbarth	Manfred	3 Parkway Center, Ste. 315	Pittsburgh	PA	15220	Hartung, Kung & Co.
Haggin	Joseph H. S.	176 W. Adams St., Ste. 1433	Chicago	IL	60603	Chemical & Engineering News

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Hall	Scott	4800 E. 63rd Street	Kansas City	MO	64130	Burns and McDonnell
Hanson	Michael A.	208 S. La Salle St.	Chicago	IL	60604	U.S. Steel Corporation
Harms	Russell E.	6200 Oak Tree Boulevard	Independence	OH	44131	Davy-McKee, Inc.
Heeney	John	2001 Spring Rd.	Oakbrook	IL	60521	Brown & Root, Inc.
Hendrickson	Tedford M.	900 Agnew Road	Pittsburgh	PA	15227	Jones & Laughlin Steel Corp.
Hendriks	Robert V.	MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
Henz	Donald J.	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Herlihy	Jim	401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Hesse	Carolyn S.	309 W. Washington	Chicago	IL	60606	State of Ill., Pollution Control Board
Hickman	Constance	20th & State Streets	Granite City	IL	62040	National Steel Corporation
Hilovsky	Robert	22850 Cooley Drive	Colton	CA	92324	So. Coast Air Quality Management Dist.
Hoffman	Al	505 King Avenue	Columbus	OH	43201	Battelle-Columbus Laboratories
Hofstein	Harold	1250 Broadway	New York	NY	10001	Hydrotechnic Corporation
Holowaty	Michael O.	3001 E. Columbus Drive	East Chicago	IN	46312	Inland Steel Company
Hurt, Jr.	George	230 S. Dearborn St.	Chicago	IL	60604	U.S. EPA, Region V
Innace	Joseph J.	1221 Ave. of Americas	New York	NY	10020	McGraw Hill, 33 Metal Producing Mag.
Jablin	Richard	Station 1, Box P-J	Wrightsville Beach	NC	28480	Richard Jablin & Associates
Jacenty	Jeffrey W.	2845 Clearview Dr.	Atlanta	GA	30362	The CADRE Corporation
Jackson	Walter E.	600 Grant St.	Pittsburgh	PA	15230	U. S. Steel Corporation
Jaeger	Rudy	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Jeffrey	John D.	Burlington Road	Bedford	MA	01730	GCA/Technology Division
Johnson	Byron G.	1500 Frontage Road	Northbrook	IL	60062	Hazleton Environmental Sciences Corp.
Johnson, Jr.	John H.	345 Courtland Street	Atlanta	GA	30308	U.S. EPA
Jones	N. Stuart	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Kammermayer	H.	P. O. Box 460	Hamilton, Ontario	Canada	L8N 3J5	Dominion Foundries & Steel Co.
Kane	John F.	One Penn Plaza	New York	NY	10001	Envirotech Corporation
Kassim	Antoinette	Office of Technology Assessment	Washington	DC	20510	U.S. Congress
Keith	W. H.	401 M Street, S. W.	Washington	DC	20406	U.S. EPA
Keller	Thomas G.	Martin Tower	Bethlehem	PA	18017	Bethlehem Steel Corp.
Kemner	William	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Kerecz, Jr.	Bela J.	Homer Research Labs	Bethlehem	PA	18016	Bethlehem Steel Corp.
Kiessling	Frank J.	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Kinder	Thomas J.	2735 Broadway	Cleveland	OH	44114	City of Cleveland
Kluge	Charles	9542 Hardpan Road	Angola	NY	14006	The Duriron Co., Inc.
Knechtges	Richard C.	6801 Brecksville Road	Independence	OH	44131	Republic Steel Research
Kolnsberg	Henry J.	125 Silas Deane Highway	Wethersfield	CT	06109	TRC - Environmental Consultants, Inc.
Kopta	David	P. O. Box 2500	Salt Lake City	UT	84110	Utah Department of Health
Krikau	F. G.	150 W. 137th Street	Chicago	IL	60627	Interlake, Inc.
Krzymowski	Cezary	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Kunz	Joseph W.	6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Lace, Sr.	Robert H.	P. O. Box 6428	Fort Myers	FL	33901	The Munters Corporation
Landreth	Ronald R.	3001 E. Columbus Drive	East Chicago	IN	46312	Inland Steel Company
Larson	Gregory L.	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Lawrence	James R.	S-3556 Lake Shore Road	Buffalo	NY	14219	Bethlehem Steel Corp.
Lawson	Allan T.	P. O. Box 1237	North Sydney	Australia	2060	The Broken Hill Proprietary Company Ltd
Lee	John R.	11236 So. Torrence Ave.	Chicago	IL	60617	Interlake, Inc.
Leming, Jr.	John W.	1636 Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corp.
Levine	Sy	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Lisk	Ian	1301 South Grove	Barrington	IL	60010	Pollution Engineering Magazine
Lower	George W.	Department of Metallurgy	Houghton	MI	49931	Michigan Technological University

Manda	J. G.	20th & State Streets	Granite City	IL	62040	National Steel Corporation
Margolin	Stanley V.	Acorn Park	Cambridge	MA	02140	Arthur D. Little, Inc.
Martzolf	J. A.	9400 Cherry Avenue	Fontana	CA	92335	Kaiser Steel Corporation
Maslany	Thomas J.	6th & Walnut Streets	Philadelphia	PA	19426	U.S. EPA, Region III
Mata	Cora	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
McAdams	Lelia M.	Middletown Works	Middletown	OH	45043	Armco, Inc.
McCluskey	Ernest J.	3210 Watling Street	East Chicago	IN	46312	Inland Steel Company
McCrillis	Robert C.	IERL, MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
McDermott	James E.	230 S. Dearborn St.	Chicago	IL	60604	U.S. EPA
McMeans	William L.	4600 N. Clarendon, Ste. 1306	Chicago	IL	60640	Apollo Tech
Mears	Connally E.	1860 Lincoln St.	Denver	CO	80203	U.S. EPA, Region VIII
Meffert	Donald P.	12161 Lackland Road	St. Louis	MO	63141	Envirodyne Engineers, Inc.
Merritt	John E.	1406 Chamber of Commerce Building	Pittsburgh	PA	15219	Koppers Co., Inc.
Meyer	Eugene F.	230 S. Dearborn Street	Chicago	IL	60604	U.S. EPA, Region V
Miceli	Joseph V.	485 Clyde Avenue	Mountain View	CA	94042	Acurex Corporation
Milhau	Alain	74 Boulevard du General Leclerc	92521 Neuilly	France		French Environmental Protection Agency
Miller	A. Leslie	Koppers Building	Pittsburgh	PA	15219	Koppers Co., Inc.
Miller	Bruce	345 Courtland St., N. E.	Atlanta	GA	30308	U.S. EPA, Region IV
Miner	Robert P.	One Penn Plaza	New York	NY	10580	Chemico Air Pollution Control Corp.
Molnar	James A.	3001 Miller Road	Dearborn	MI	48121	Ford Motor Co.
Mueller	Patrick	1129 Bellwood Avenue	Bellwood	IL	60104	Faville Le Vally Corp.
Murphy	Samuel M.		Frankfort	KY	40601	Kentucky Div. of Air Pollution Control
Nagano	Kenichi	2001 Spring Rd, Commerce Plaza N.	Oakbrook	IL	60521	Nippon Steel Corp.
Nakamura	Masatoshi	280 Park Avenue	New York	NY	10017	Kawasaki Steel Corp.
Nelson, Jr.	Theodore W.	223 W. Jackson Blvd.	Chicago	IL	60606	Peter F. Loftus Corp. (Illinois)
Neufeld	Ronald D.	939 BEH	Pittsburgh	PA	15261	University of Pittsburgh
Nicola	Art	32nd St.	Pittsburgh	PA	15201	Pennsylvania Engineering Corporation
Nicoll	Harry E.	1991 Lee Road	Cleveland	OH	44118	J. P. Bergren Co.
Nogawa	Hirotoshi	345 Park Avenue, 41st Floor	New York	NY	10022	Nippon Steel USA, Inc.
Notar	John	230 S. Dearborn St.	Chicago	IL	60604	U.S. EPA, Region V
Ochsenfeld	Joe	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Oda	Terry	6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA
Onsgard	Henry	230 S. Dearborn (5 AHAF)	Chicago	IL	60604	U.S. EPA
Parikh	Lax	2845 Clearview Road	Atlanta	GA	30362	The CADRE Corporation
Pasztor	Laszlo	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Paul	Ralph L.	505 King Avenue	Columbus	OH	43201	Battelle-Columbus Laboratories
Pekron	Phillip G.	230 S. Dearborn, Air Enforcement	Chicago	IL	60604	U.S. EPA
Perl	Conrad	100 King St. W.	Hamilton, Ontario	Canada	L8N 3T1	The Steel Co. of Canada, Ltd
Peterson	Joseph C.	515 So. Harmon	Indianapolis	IN	46225	Crown Environmental Control Systems,Inc
Phelps	Richard G.	3210 Watling Street	East Chicago	IN	46312	Inland Steel Company
Pike	Daniel E.	145 Cedar Lane	Englewood	NJ	07631	Neptune AirPol, Inc.
Piper	Steve	Burlington Road	Bedford	MA	01730	GCA/Technology Division
Plaks	Norman	IERL, MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
Polglase	William L.	MD-13	Research Triangle Park	NC	27711	U.S. EPA, RTP
Purdy	Ralph W.	2800 Grant St.	Pittsburgh	PA	15219	National Steel Corporation
Radigan	Patrick	20th & State Streets	Granite City	IL	62040	National Steel Corporation
Ramani	R. V.	152 Floral Avenue	Murray Hill	NJ	07974	Wilputte Corporation
Ramchandani	Chandru	135 St. Clair Ave., West	Toronto, Ontario	Canada	M4V 1P5	Ontario Ministry of the Environment
Reilly	Robert P.	P. O. Box 988	Buffalo	NY	14240	Andco Environmental Processes
Riddle	M. J.	W. P. C. D., E. P. S.	Ottawa, Ontario	Canada	K1A 1C8	Environment Canada

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Riley	William J.	Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corp.
Rodgers	Peter	Staveley Works, Chesterfield	Derbyshire	England	S43 2PA	British Steel Corp. (Chemicals) Ltd.
Rosenthal	Steve	230 S. Dearborn, 5 AHAP	Chicago	IL	60604	U.S. EPA
Rudy	Bill	147 E. Second St.	Mineola	NY	11501	The Ducon Co., Inc.
Ruggiero	Dominick D.	1250 Broadway	New York	NY	10001	Hydrotechnic Corporation
Ruppersberger	John	MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
Sandonato	Henry L.	584 Delaware Avenue	Buffalo	NY	14202	NYS Dept. Environmental Conservation
Schaffer	Robert B.	401 M Street, S. W., WH-552	Washington	DC	20460	U.S. EPA
Schraff	Christopher R.	37 W. Broad St.	Columbus	OH	43215	Porter, Wright, Morris & Arthur
Schreibeis	Lee	1635 Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corp.
Schuldt	A. A.	Stelco Tower, 100 King St., W.	Hamilton, Ontario	Canada	L8N 3T1	Steel Company of Canada, Limited
Sharpe	Robert	2200 Churchill Road	Springfield	IL	62706	Illinois EPA
Sharpe	Susan	MD-62	Research Triangle Park	NC	27711	U.S. EPA, RTP
Shetzler	James E.		Wilmington	DE	19898	E. I. du Pont de Nemours & Co., Inc.
Shoup	Stefan P.	3210 Watling	East Chicago	IN	46312	Inland Steel Company
Siebenberger	L. G.	20th & State Streets	Granite City	IL	62040	National Steel Corporation
Silverman	Stuart	EN-341, 401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Silvermintz	Mark	EN-341, 401 M Street, S. W.	Washington	DC	20460	U.S. EPA
Smith	Dan	2845 Clearview Dr	Atlanta	GA	30360	The CADRE Corporation
Smith	David B.	Prudential Center	Boston	MA	02199	Chas. T. Main, Inc.
Smith	William M.	2800 Grant Building	Pittsburgh	PA	15215	National Steel Corporation
Sokolowski	Jerzy Z.	320 North Clark St.	Chicago	IL	60610	Energy and Environmental Protection
Soukup	Stanley	152 Floral Avenue	Murray Hill	NJ	07974	Wilputte Corporation
St. Pierre	George R.	2041 N. College Road	Columbus	OH	43210	Ohio State University
Staehle	William	One E. Wacker Drive	Chicago	IL	60601	Illinois-Indiana Bi-State Commission
Stagias	N. J.	152 Floral Avenue	Murray Hill	NJ	07974	Wilputte Corporation
Stebbins	Lloyd H.	P. O. Box 5200	Cherry Hill	NJ	08034	Stone & Webster Engineering Corporation
Steiner	Bruce A.	P. O. Box 600	Middletown	OH	45043	Armco, Inc.
Steiner	James	485 Clyde Avenue	Mountain View	CA	94042	Acurex Corporation
Stensland	John G.	605 N. Court, Ste. 125	Palatine	IL	60067	Envirotech Air Quality Control Group
Stiles	Lawrance	22850 Colton Drive	Colton	CA	92324	So. Coast Air Quality Management Dist.
Stromness	N. R.	State Street	Clairton	PA	15025	U.S. Steel Corporation
Szuhay	Lawrence A.	6801 Brecksville Road	Independence	OH	44141	Republic Steel Corporation
Tartaron	Gary	327 Fifth Avenue	Pittsburgh	PA	15222	Salvucci Engineers, Inc.
Tejuja	Ramesh	1330 West Michigan St.	Indianapolis	IN	46206	Indiana State Board of Health
Telford	Anton M.	2200 Churchill Rd., Air Permit Sec.	Springfield	IL	62704	Illinois EPA
Tennyson	Richard P.	P. O. Box 6428	Fort Myers	FL	33901	The Munters Corporation
Thayil	Boniface S.	230 S. Dearborn, AHRD-Air Programs	Chicago	IL	60604	U.S. EPA, Region V
Thomas	Jean G.	Somerton Road	Trevose	PA	19047	Betz Laboratories, Inc.
Thompson	Ronald J.	P. O. Box 600	Middletown	OH	45043	Armco, Inc.
Throop	William	P. O. Box 1067	Waukesha	WI	53187	Envirex, Inc.
Tomes	Steve	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Tower	Kevin C.	125 Silas Deane Highway	Wethersfield	CT	06033	TRC - Environmental Consultants, Inc.
Traina	Vincent P.	2130 West Park Drive	Lorain	OH	44053	R. E. Warner and Associates
Trenholm	Andrew	425 Volker Boulevard	Kansas City	MO	64110	Midwest Research Institute
Truskowski	Steve	9542 Hardpan Road	Angola	NY	14006	The Duriron Co., Inc.
Tucker	A. L.	3001 Dickey Road	East Chicago	IN	46312	Jones & Laughlin Steel Corp.
Turk	Diana	2970 Maria Avenue	Northbrook	IL	60062	McIlvaine Co.
Twork	John V.	North Point Boulevard	Sparrows Point	MD	21219	Bethlehem Steel Corp.
Umeno	Eiji	Avenue Hamoir 12/14	B-1180 Brussels	Belgium		International Iron and Steel Institute

Vallejera	Rico	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA
Villalobos	Mel	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Voruz	Ted	2901 Butterfield	Oakbrook	IL	60521	NALCO Chemical
Wall, Jr.	William T.	1901 S. Prairie Avenue	Waukesha	WI	53186	Envirex, Inc.
Wallace	Anna W.	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Weakland	J. M.	1 Oliver Plaza	Pittsburgh	PA	15222	Dravo Corporation
Wentz	Jeffrey	465 Fullerton Avenue	Elmhurst	NJ	60126	Pacific Environmental Services
Wettlaufer	T. N.	North Point Boulevard	Sparrows Point	MD	21219	Bethlehem Steel Corp.
Whitmore	Julie	1232 Simpson St.	Evanston	IL	60201	BNA
Wingard	Connie	3210 Watling St.	East Chicago	IN	46312	Inland Steel Company
Wise	Steve	1400 South, Route 31	McHenry	IL	60195	Lodge-Cottrell
Withrow	William	1701 S. First Avenue	Maywood	IL	60153	Illinois EPA, Div. of APC
Wojciechowski	Edward A.	230 S. Dearborn St.	Chicago	IL	60453	U.S. EPA
Wolfe	Joel Z.	223 W. Jackson Blvd.	Chicago	IL	60606	Peter F. Loftus Corp. (Illinois)
Wood	C. W.	20521 Chagrin Blvd.	Cleveland	OH	44122	Luria Brothers & Co., Inc.
Yocom	John E.	125 Silas Deane Highway	Wethersfield	CT	06109	TRC - Environmental Consultants, Inc.
Young	Jack	Somerton Road	Trevose	PA	19047	Betz Laboratories, Inc.
Young, Jr.	Earle F.	1000 16th Street, N. W.	Washington	DC	20036	American Iron and Steel Institute
Yuhnke	Bob	Suite 2610, 59 East Van Buren St.	Chicago	IL	60605	Citizens for a Better Environment
Zamco	Miles	2200 Churchill Road	Springfield	IL	62706	Illinois EPA, Div. of APC
Zielinski	Denis	6th & Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Zwikl	James R.	200 Neville Road	Pittsburgh	PA	15225	Shenango, Incorporated

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